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Coal - A Sustainable Energy Source for Meeting Global Energy Demand till 2030

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A B S T R A C T

By all accounts, the modern sense of the words ‘Sustainability of Coal’ entered the lexicon in 1987 with the publication of Common Future, by the United Nations World Commission on Environment and development (also known as the Brundtland commission after its chair, Norwegian diplomat Gro Harlem Brundtland). That report defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Or, in the words of countless kindergarten teachers, “Don’t take more than your share.” Mahatma Gandhi once said: "The Earth provides-enough to satisfy everyone's needs but not any one's greed." The term sustainability nowadays is commonly used in reference to energy sources such as Coal, oil & natural gas which are prime non-renewable energy sources. Besides economic and social requirements, sustainable energy depends on reliability, efficiency, resilience, adaptability and responsible environmental management. Coal production, based on reserves for more than 100 years, provides reliable economic energy, combined with an innovative and effective environmental management regime. Although renewable energy resources are a priority for the future, hydro, wind, solar, biomass, wave and tidal power are not yet viable enough to produce sufficient base load power**.** This paper emphasizes on Sustainable Development and utilization of the limited non-renewable energy sources by providing for the present, without compromising the needs and also for the life of future generations.

1. Introduction

The energy sources are categorized as Renewable and Non-renewable energy sources:

Renewable Energy Sources: Energy sources based on natural cycles that are replenished in a relatively short time frame are called renewable energy sources. These resources can be managed to provide long-term power needs and will not run out. Trees and crops can be replanted. The sun shines each day. Rivers flow to the sea and winds can be expected to continue to blow. Examples of renewable energy systems include geothermal energy, solar energy, biomass energy, wind energy and hydropower.

Non-Renewable Energy Sources: Energy sources based on limited reserves created several million years ago by unique geological and physical conditions. Such reserves will eventually run out as the available deposits are depleted. The most common of these types of fuels are often referred to as fossil fuels and include petroleum, coal, and natural gas.

The key to a sustainable future, with the standard of living we have all grown accustomed to, is the supply of sustainable

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power. Sustainable power supplies must satisfy several important criteria including:

- Reliability (continuity of supply - day in, day out, 24 hours per day)
- Efficiency (minimum of waste)
- Resilience (ability to recover from disturbance and resume normal delivery)
- Adaptability (taking advantages of improvements and new possibilities)

Renewable energy sources do not have all these qualities. Coal provides all four of these sustainability requirements, long-distance supply system with no stockpile capacity close to the users & renewable are subject to the elements. For instance, wind farms provide power for less than 30% of the time. Reliability & Resilience are gained by having viable, alternative energy supply industries. Without Reliability and Resilience, there will not be sustainable energy.

Objectives of the Study

1. To study energy resources and their management
2. To study greenhouse effect and global warming
3. To study low emission and fuel efficient technologies
4. To roll of coal in energy mix
5. To study coal as sustainable energy source for meeting global energy demand

1. Resource Management

As per International Energy Outlook 2017 (IEO2017), total world energy consumption rises from 575 quadrillion British thermal units (Btu) in 2015 to 736 quadrillion Btu in 2040, an increase of 28%. Most of the world's energy growth will occur in countries outside of the Organization for Economic Cooperation and Development (OECD), where strong, long-term economic growth drives increasing demand for energy. Non-OECD Asia (including China and India) alone accounts for more than half of the world's total increase in energy consumption over the 2015 to 2040 projection period. By 2040, energy use in non-OECD Asia exceeds that of the entire OECD by 41 quadrillion Btu as stated in the IEO2017.

With its rising energy needs, India has emerged as the fourth largest energy consumer of the world after the US, China and Russia, but its per capita energy consumption remains lower than that of developed countries, says a report. India's economy grew at an annual rate of approximately 7 percent since 2000 and proved relatively resilient to the 2008 global financial crisis.

Table-1: Largest Energy Consumers of the World

Rank	Country/Region	Electricity consumption (kW·h/yr)	Year of Data	Population	As of	Average energy per capita (kWh per person per year)	Average power per capita (watts per person)
—	World	21,776,088,770,300	2014	7,322,811,468	2016	2,674	339
1	China	5,920,000,000,000	2016	1,373,541,000	2016	4,310	492
2	United States	3,913,000,000,000	2014 EST.	323,995,528	2016	12,077	1378
3	Russia	1,065,000,000,000	2014 EST.	142,355,415	2016	7,481	854
4	India	1,001,191,000,000	2015 EST.	1,266,883,598	2016	1122	87

The experience of massive energy shortfalls and blackouts are normally because of a reliance on any one resource e.g. natural gas, provides a stark example of what can go wrong, and what can be avoided by a balanced energy supply including coal. There is a common perception that power situation can be changed by use of renewables overnight and this is politically, socially and economically damaging. Sustainable energy is not just about the transition from fossil fuels to renewable energy sources, particularly over the next 20-50 years. Renewables are undeniably priority energy resources for consideration, support and development but will need to be balanced with fossil fuels for sustainable energy delivery i.e. proper energy mix.

Proper resource management is fundamental requirement to Sustainable Development. It needs to plan the most effective use of energy sources, particularly fossil fuels, such that these are not wasted but are protected and optimized to produce the best social, economic and environmental outcomes. Fossil fuels have differing uses, differing initial values and differing value-adding capacities. The natural gas, for instance, is a fossil fuel capable of numerous high-value export products and easy application to reduce emissions in transport vehicles. Thus it is a waste to use this natural resource unnecessarily in basic power generation. It is necessary that the fossil fuels be used with due attention to sustainable utilization of their use so as to mitigate their ill effects.

The effective use of non-renewables and renewables is most important in any country's energy mix for attaining sustainable development and is highly dependent upon proper resource management.

Ability of developing countries to reduce poverty, grow sustainably, and maintain opportunities for future generations rests on prudent management and use of their natural resources. Protection of land, forests, waterways, and wildlife is particularly important due to their contributions to food production, fuels, shelter, medicines, livelihoods, and cultural values. Preserving biodiversity by maintaining a variety of plant and animal species and protected ecosystems provides resilience in the face of environmental changes. As biodiversity is lost, communities become more vulnerable and valuable genetic resources are diminished. Those living in poverty are typically the hardest hit by degraded ecosystems and loss of biodiversity and forest resources, due to associated declines in clean air and water, higher prevalence of disease, and increased vulnerability to natural disasters. Without alternatives, poor communities tend to overuse or under employ natural resources that are important for the protection of beneficial goods and services for domestic use and export.

As economies grow, environmental quality tends to decline, with humans at fault for the bulk of environmental problems. Activities such as logging, mining, industrial development, the exploitation of plant and animal resources, and conversion of natural habitats into cultivated land lead to ecological degradation, species extinction, and pollution of the environment. Breaking this pattern requires a focus on more efficient resource use and environmental protection. Energy plays a key role in the management of natural resources and the transition to environmentally sound economic growth. The selection, use, and development of cleaner energy sources have a direct effect on the environment, with related health, economic, and social benefits.

Energy Resource management includes planning and operation of energy-related production and consumption units. Objectives are resource conservation, climate protection and cost savings, while the users have permanent access to the energy they need. It is connected closely to environmental management, production management, logistics and other established business functions. The VDI-Guideline 4602 released a definition which includes the economic dimension: "Energy management is the proactive, organized and systematic coordination of procurement, conversion, distribution and use of energy to meet the requirements, taking into account environmental and economic objectives". VDI (Verein Deutscher Ingenieure, English: Association of German Engineers) is an organization with over 150,000 engineers and natural scientists. The association promotes the advancement of technology and represents the interests of engineers and of engineering businesses in Germany. In the Energy Utilisation technical committee of the VDI Society for Energy Technology, specialists from science, industry and administration are working voluntarily and at their own responsibility on the preparation of VDI guidelines for rational energy utilization in industrial enterprises. One particular focus of this work is energy management.

2. Greenhouse Effect & Global Warming

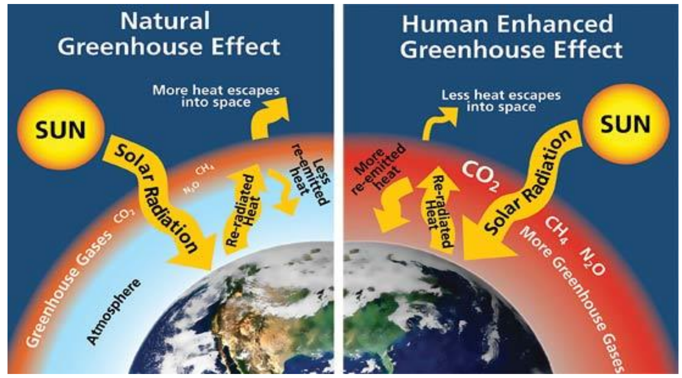

Fig. 1: Green House Effect

The "greenhouse effect" is a natural phenomenon caused by "insulating" gases in the atmosphere that allow life on Earth as we know it today – without it the Planet would be 20°C cooler. The "enhanced greenhouse effect" is that attributed to man-made gaseous contributions to the atmosphere – which are around 4% of the total greenhouse effect.

The possible impacts of global warming could include rising sea levels, changes in ecological systems, changes in agricultural domains, droughts, floods and disease spread. Although these predictions are yet to be validated, the world has accepted the need to address global emissions based on the precautionary principle. Regardless of the unknowns, it makes sense to be more efficient and thus reduce emissions.

Climate change and greenhouse emission abatement has been internationally embraced although there are strong opinions around the world that there are many inconsistencies in the science driving the politics. One thing is certain, Man's activities are adding to the Earth's atmosphere with rising carbon dioxide levels due to industrialization. Less certain is the extent to which this is responsible for global warming. Even more uncertain are the likely impacts of global warming on sea levels, agriculture, health, water resources, ecosystems and weather. Thus, the argument maintaining the greenhouse momentum is that we cannot afford to wait for perfect knowledge as it will maybe take centuries to confirm climate model predictions.

The temperature, we experience is a function of energy from the Sun being trapped near the Earth's surface by a small fraction (2%) of the atmosphere called "greenhouse gases", mostly water vapour (67%), in the atmosphere. There have been many causes of temperature change during the Earth's history, well before the advent of man and before the Industrial Revolution.

Regardless, there has been so much reporting on "Global Warming" that most people, including laymen, eminent scientists, environmentalists, politicians and journalists, accept significant climate change is being caused by human activities. Also generally accepted that are the predictions of looming disaster, based on historical data and computer modeling. The Earth's natural CO_2 cycle involves massive annual amounts of CO_2 movement in and out of the atmosphere, some 200 billion metric tons. Human activities (anthropogenic) add about 7 billion metric tons, <5% of the annual exchange. This is claimed to be enough to put the system out of balance – with Nature only absorbing about half of Man's emissions.

Humans have likely had an effect on climate through population growth, agriculture, industrial activity, building and transport. The records show global warming over the past 150 years and a large percentage increase in CO_2 contributed to by anthropogenic output. The general concern is for ongoing rising CO_2 and other greenhouse gas levels as these gases remain in the atmosphere for decades to centuries – leaving a long-term legacy of dubious consequences for the planet. These could include impacts on health, sea levels, storms, agriculture, water availability, flooding ecosystems and so on. The desire to radically change our socioeconomic world to reduce CO_2, through suggested measures such as removal of the combustion engine, reduction of fossil fuel usage or cessation of coal mining, has yet to take into account the practicalities of such a move – or adequate replacement fuel options. Carbon dioxide abatement is not a fad that will go away and, notwithstanding coal fuel is vital to the world economy, it is the most targeted greenhouse source. The latest example of pollution at Delhi capital of India is as under:

On 7th November 2017, air pollution level at Delhi, rose to nearly 50 times that of London average. A public health emergency has been declared by doctors in Delhi as air quality in the world's most polluted capital city plunged to levels likened to smoking at least 50 cigarettes in a single day. The instruments in the city could measure with some recording an Air Quality Index (AQI) maximum of 999. The Indian Medical Association said the country's capital was suffering a health emergency. The Annual mean PM2.5 levels for selected cities, micrograms per cubic meter are given below to compare with Delhi's unhealthy pollution level.

Fig. 2: Pollution at Delhi on 7th November 2017

Table-2: Revised PM2.5 AQI breakpoints

AQI Category	Index Values	Revised Breakpoints ($\mu g/m^3$, 24-hour average)
Good	0 - 50	0.0 – 12.0
Moderate	51 - 100	12.1 – 35.4
Unhealthy for Sensitive Groups	101 – 150	35.5 – 55.4
Unhealthy	151 – 200	55.5 – 150.4

Table-3: Annual mean PM2.5 levels for selected cities of World

City	Country	Pollution Level
Stockholm	Sweden	6
Los Angeles	US	11
Tokyo	Japan	15
London	UK	15
Paris	France	18
Beijing	China	85
Delhi	**India**	**122***

(***PM2.5 levels in Delhi on 7th November 2017 – 710**)

3. Low Emissions technology

Fossil fuels provide around 75% of the world's energy needs and, being diminishing resources, alternatives will eventually be required. Nuclear energy, although also finite, may need expanded usage to maintain required energy supplies as renewable energy sources are cost restrictive and some have serious associated environmental impacts.

Carbon Dioxide (CO_2) emissions from coal-fired power stations are reduced by approximately 3% for every 1% improvement in burning efficiency. In this context, the retrofitting and/or replacement of existing coal-fired power plant with new-technology generation capacity can deliver a greater greenhouse benefit than some renewable technologies. This requires the introduction of "Clean Coal" technologies – a term variously used to describe a range of technologies from high-efficiency generation systems to the ultimate, zero emission power production. Coal will remain a substantial part of the energy mix in the foreseeable future as new technologies improve efficiencies and reduce emissions. Power station thermal efficiency has a major effect on greenhouse gas production such that improving efficiency results in a reduction in emissions and coal consumption. A 1% improvement in power station efficiency delivers a 3% reduction in CO_2 emissions.

There is another strong case for taking the improved efficiency path using coal for power generation. Renewable energy resources are not sufficiently reliable to ensure security of electricity supply. For example, wind turbines typically operate a low percentage of the time – being at the mercy of the vagaries of nature – the wind blowing. For instance, installed wind generation capacity (10,543MW) in Germany during

2002, only produced 2.5% of the potential power due to poor wind conditions. To replace a 300MW coal station would require 600 windmills, assuming 100% utilization. Bearing in mind utilization is < 30% then nearly 2,000 windmills would be required to theoretically deliver 300MW. Whether 600 or 2,000, windmills leave a much larger footprint than a coal-fired power station.

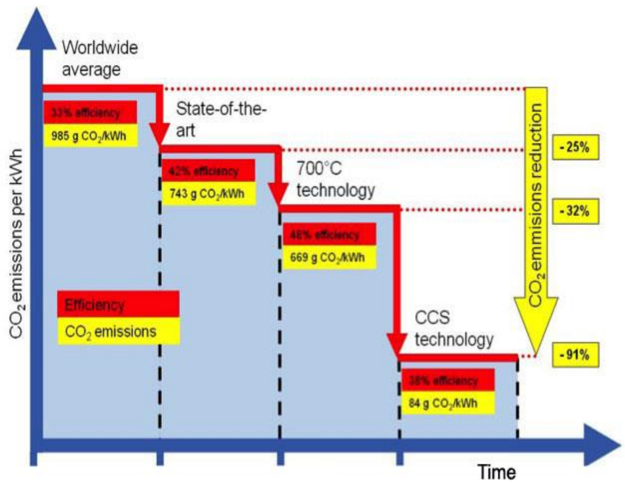

Fig. 3: Effect of Technology upgradation on CO_2 emission.

There is a strong case to say that new-generation, higher-efficiency power stations, replacing older stations, will deliver as good CO_2 reductions at far less cost and a much smaller footprint than windmills. While there is a place for renewable for electricity generation e.g. wind generation, adding windmills to the system can reduce the cost effectiveness of conventional generation, as wind generation still needs conventional power station back up in "calm" times. The inevitable conclusion is that the solution is greater efficiency in coal generation, even retrofitting, rather than renewables for the sake of renewables.

4. Fuel Efficient Technologies

Improvements beyond 40% efficiency for conventional pulverized fuel (pf) stations can be achieved with advanced combustion chamber technology with "Supercritical" (40-45% efficiency) and "Ultra-supercritical" (>45% efficiency) systems. The impact of efficiency is large on greenhouse gas reduction. For instance, a supercritical plant replacing would reduce greenhouse emission by around 50%. Advanced materials for pulverized fuel plants could raise efficiencies to nearly 50%. In addition, gains can be made by co-firing with biomass, such as sawmill waste, to reduce emissions by over 10% without loss of power station efficiency.

In the longer-term, the Integrated Gasification Combined Cycle (IGCC) offers one of the most efficient and "greenhouse friendly" coal-based electricity generation processes. Here coal is gasified into fuel that is subsequently burnt in a combined cycle turbine plant with overall thermal efficiency of 44-45%. One advantage of gasification is the ability to use low-quality fuels and fuels with environmental stigmas – high in metals, nitrogen and sulfur - and it greatly simplifies CO_2 recovery, particularly with the use of pressurized, oxygen-blown gasification systems. Similar O_2/CO_2 combustion technology is applicable to conventional power stations with CO_2 concentrated to >95% by displacing air with O_2.

Gas turbines are currently considered an extremely attractive option because of higher efficiencies and lower consequent emissions, advantages in size options, compactness, capital cost, time to construct and rapid start up. The combined cycle system, producing an overall thermal efficiency of 45-50%, is nearly the least greenhouse gas intensive of the fossil fuel technologies.

Following figure indicates technology maturity curve for IGCC with capital requirement and technology risk.

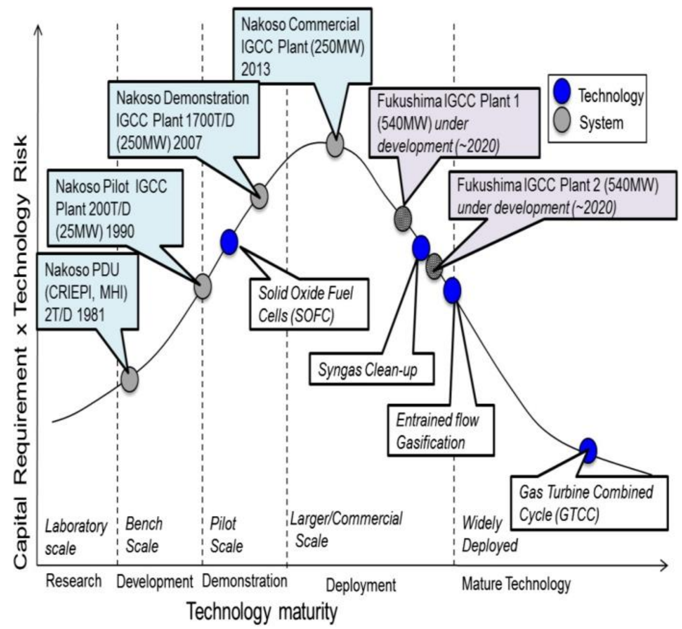

Fig. 4: Technology Maturity Vs Capital Requirement and Technology Risk

Utilization of biomass in Integrated Combined Cycle systems is a popular concept as biomass is deemed a form of renewable energy. Gasification of the biomass through drying and heating the material produces a fuel gas suitable for combustion in a boiler or gas turbine. Ultimately, zero emission technology may be the savior of fossil fuels. Geological disposal of CO_2 by reinjection into expired gas fields is already done. An alternative is to liquefy the CO_2 and pump it to a sea floor depth of at least 1km where it should remain having formed a crystal hydrate with seawater.

5. Role of Coal in Energy Mix

Renewable energy sources (hydro, wind, solar, biomass, wave and tidal) and technology can provide some generation capacity but the current/variable costs are often not viable (except hydro) and would be unable to meet demand. Each fossil fuel still has a role to play in the world's energy mix. Coal has some advantages over oil and gas, being abundant and well spread. Developed countries are reducing fossil fuel emissions, however less developed countries are actually increasing fossil fuel usage – herein lies the a fundamental flaw in the Kyoto Protocol.

Reality must dictate a future for coal. It will be based on a cleaner electricity generation industry. Of all the currently investigated clean coal technologies, coal gasification technology is mooted to have the best chance of success. An IGCC power plant can produce electricity as well as hydrogen for transportation fuels and for "distributed generation" in the future. The alternatives to utilizing coal are grim and unpalatable at present, requiring either incredibly expensive alternative energy technologies, or the burning of more oil and gas, or, if not, an increase in nuclear generation. Sustainability lies in greater energy efficiency and less energy losses. Despite the rapid growth of non-fossil energy sources, the composition of the energy basket will largely remain the same, and fossil fuels – oil, natural gas, and coal – will remain the main suppliers of energy, accounting for over 78% of the energy supply in 2030. In summer 2004, the World Energy Council published a Study on "Sustainable Global Energy Development: the Case of Coal". The Study was aimed at developing an internationally consistent reply to the question whether and to what extent coal use could be economic and sustainable in meeting global energy demand to 2030 and beyond. It covers markets, trade and demand, mining and combustion technologies, restructuring and international policies, and perspectives.

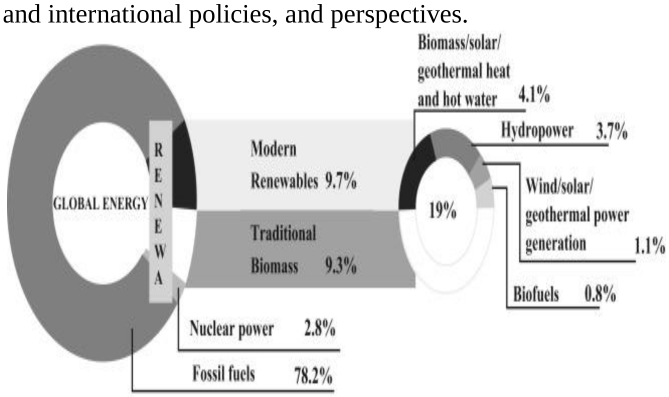

Fig. 5: Sustainability of Fossil fuels for Meeting Global Energy Demand till 2030

It considers both, the contribution that coal could make to economic development as well as the need for coal to adapt to the exigencies of security of supply, local environmental protection and mitigation of climate change. It suggests that coal will continue to be an expanding, cheap foundation for economic and social development. Backed by its vast and well-distributed resource base, coal will make a significant contribution to eradicating energy poverty and coal can be and will be increasingly clean, - at a bearable cost in terms of technological sophistication, and at little cost in terms of international technology transfer and R&D in CO_2 sequestration. For this to happen, even-handed energy and environmental policies are needed, not ideologies. Moreover, a more pro-active involvement of the coal and power industries is needed in "globalizing" best technical and managerial practices and advocating coal's credentials.

In 2030, the issue is one of resource constraint and opportunity. The concern is not so much the related rise of energy prices (which, as was pointed out above, had a beneficial impact on efficiency), or their impact on customers (average world income had doubled between 2000 and 2030 59), or a physical scarcity (unconventional fossil fuel resources are plentiful in 2030). Rather, the concern is the inefficient and unprofitable use, i. e. combustion, of the valuable organic components of fossil fuels. Experience since the 2020s had shown that chemical processing, particularly into clean transportation fuels, enabled a fuller and more profitable exploitation of the energy raw material. Coal's comparatively favorable resource base and its price competitiveness could make chemical processing into synfuels and gas a growth market for coal. Under market conditions, coal-based synfuels could cover by 2050 some 14 % of world transportation fuel consumption. At a price: the coal industry would have to change: hitherto separate enterprises in coal mining, gasification, liquefaction and coal bed methane drainage, would have to integrate into necessarily globally operating oil and gas refining, product transportation and distribution businesses; the business strategy of coal companies would have to be subdued to the strategies of the processing and delivery conglomerates. Whether servicing the traditional power generation market or the clean transportation fuel market, coal no longer reaches the end user as "coal". The term "coal" is replaced by brand names, which highlight the service rendered (power, mobility) without identifying the raw material (coal). Ironically, concerns expressed at the beginning of the century that the lack of public acceptance might be an obstacle to the growth of coal demand, proved unfounded: there is no direct interface any more between "coal" and the end user except in very rare cases of its direct use as a fuel or as a piece of art. The study undertaken by the WEC in 2030 on "Energy for the World of 2050" would confirm the important societal role of coal in meeting the aspirations of nations for development and sustainability. It would point to a significant but challenged role of coal in traditional power generation. And it would appraise its comeback, as a derivate, in markets, which it had lost with the advent of cheap oil and gas, - hundred years ago.

6. Conclusion

It must identify how best to maximize synergies and deal with trade-offs between the objectives of competitiveness, security of energy supply and sustainability. The framework should also take into account the longer term perspective for moving to a competitive low carbon economy in 2050, the Energy Roadmap 2050. The Roadmaps to be developed in line with the objective of reducing GHG emissions by 80 to 95% by 2050 compared to 1990 levels as part of necessary efforts by developed countries as a group. The scenarios in these Roadmaps suggested the following key findings:

1. By 2030 GHG emissions would need to be reduced by 40% to be on track to reach a GHG reduction of between

80-95% by 2050, consistent with the internationally agreed target to limit atmospheric warming to below 2°C.

2. Higher shares of renewable energy, energy efficiency improvements and better and smarter energy infrastructure are "no regrets" options for transforming the energy system.
3. For renewables, the policy scenarios in the Energy Roadmap 2050 indicate a share of around 30% in 2030.
4. Significant investments are needed to modernize the energy system, with or without decarburization, which will impact the energy prices in the period up to 2030.

The sustainable energy development can be appraised against three benchmarks:

1. The continued **availability** of energy, in sufficient quality and quantity, adapted to the changing needs of customers
2. The growing **accessibility** of energy, it being understood that the costs of supply and further energy development are covered. WEC recalls that at the beginning of the 21st century, two billion people had no access to commercial energy, while another two billion had access to unreliable and often unaffordable supplies
3. The **acceptability** of energy, i. e. its compatibility with societal concerns, be they developmental, environmental or social.

Against these benchmarks, it is to conclude that coal is:

- **Available** to meet the steeply rising demand for steam coal, while adapting the supply of coal to reduced demand. Despite the drain on reserves, those would remain huge in absolute terms and compared to oil and gas reserves.
- **Accessible**, mostly in the form of electricity, to a growing number of people. Significant productivity gains international coal prices would remain stable or increase much less than the prices of its competitors. Thus, coal would contribute notably to cutting by half, till 2030, the number of people with no or unreliable access to energy. Beyond its use in electricity generation, gasification and liquefaction of coal emerge as long-term options.
- **Acceptable** in so far as by 2030, 72 % of coal-based power generation in the world would use clean coal technologies and as methane drainage and carbon sequestration would have been increasingly practiced

However, the present Study also notes deficits and advocates remedial measures. Coal's global image does not reflect the realities of the industry. A worldwide commitment of the coal and associated industries is needed to improve the public perception of coal's real performance. International policies appear to discourage the contribution to sustainable development, which coal offers in terms of availability, accessibility and affordability, and acceptability. Hence a need to re-equilibrate international policies which should:

- Place emissions from coal into a more balanced perspective. If life cycle analysis was used and other greenhouse gases were taken into account, electricity generation from fuels other than coal would show similar or even higher GHG emissions.
- Acknowledge that the projected increase in annual emissions of carbon dioxide from coal between 2001 and 2025 of 1.1 billion tons of carbon equivalent will be less than the increased amount projected for either natural gas (1.3 billion tons) or oil (1.5 billion tons)
- Acknowledge the contribution which coal can make to social and economic development and energy security
- Avoid instruments which discriminate coal; rather encourage a more efficient and clean use of coal in power generation, including through Joint Implementation, Clean Development Mechanisms and emission trading
- Supplement ongoing information exchanges on carbon sequestration by related funding of R&D initiatives
- Assist developing countries in acquiring clean coal technologies
- Encourage the worldwide application of more effective SO_2, NOx and dust emission standards for new power plants; this would also reduce the regulatory uncertainty affecting the design of clean coal technologies.
- Encourage a transparent and representative reporting system on health and safety practices in coal mining, as a basis for the broad deployment of good practices

In view of above it is necessary that targets be set by all the concerned including developing countries to arrest significant increase of CO2 emissions. It is necessary that the coal industry and power equipment manufacturers should make every effort to deploy technologies with higher efficiencies in the short and medium term and to develop carbon sequestration to technical and commercial maturity at the earliest.

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Abbreviations

IEA - International Energy Agency, IEO – International Energy Outlook

OECD - Organization for Economic Cooperation and Development

BTU – British Thermal Unit

KWh – Kilo Watt hour (1KWh = 3412.14BTU)

MW- Mega Watt

pf- Pulverized fuel

IGCC- Integrated Gasification Combined Cycle

GHG - Green House Gases

CO2 - Carbon Di-Oxide

SO2- Sulpher Di-Oxide, NOx-Nitrogen Oxides

Author's Profile

M.R. Kolhe, received the Bachelor of Engineering degree in Electrical Engineering from Visvesvaraya Regional College of Engineering Nagpur (now: Visvesvaraya National Institute of Technology, Nagpur) and M.B.A. degree from GS College of Commerce, Nagpur in 1974 and 1990, respectively. During 1975-2013, he worked in Western Coalfields Limited (Government of India Undertaking) and retired in 2013 as General Manager (Electrical & Mechanical).