Chapter-1

Introduction

1.1 General

Coal is a major source of energy for industrial growth in coal producing countries, and India is also not an exception. Coal quality remains a challenge for the coal producer and coal consumer. Due to wide variation in coal rank and grade, various methods have been used to characterize coal and for knowing the quality. Furthermore, as a result of increasing pollution threat caused by coal combustion, there is also decreasing trend to use coal for power generation in a few countries (IEA Coal 2020). Hence, there is a need to utilize coal for other purposes along with coal combustion.

Coal is a fossil fuel. It is a combustible, sedimentary, organic rock, which is composed mainly of carbon, hydrogen and oxygen. It is formed from vegetation, which has been consolidated between other rock strata and altered by the combined effect of pressure and heat over millions of years to form coal seam (Indian Minerals Yearbook 2018). It is a special type of rock that consists of organic carbonaceous matter, including macerals and inorganic minerals (Singh et al. 2017). Coal contains significant and variable amounts of largely incombustible mineral matter which is always less than 50 percent. This mineral matter primarily includes mineral and rock such as clay, pyrite, quartz, calcite and lesser amounts of other materials, depending on the mineralogical composition (Vorres 1986). Furthermore, mineral matter in coal leads to generation of fly ash after combustion in thermal power plant. The composition of fly ash depends upon the type of coal. More ash in coal leads to poor quality of coal. This increases the unnecessary transportation of non-combustible material and thereby increases the cost of coal (Rathore et al. 2017). If a coal contains 25% of ash, it means, roughly, for every four wagons of coal dispatched one wagon equivalent to ash is paid as freight charge. Hence, it is important to characterize the coal in terms of proximate and ultimate analysis along with other valuable elements present in coal for its better utilization.

Coal production reached up to 8,000 MT in 2019 worldwide (BP Statistical Review of World Energy 2020). This kind of production in the world tells us the dependency on coal till now and future. Few countries are declining coal production, however many countries still rely on coal for industrial growth (Fig. 1.1). The top five countries in coal reserves are the United States of America (249 BT), Russia (162 BT), Australia (149 BT), China (141 BT), and India (105 BT) globally (Fig. 1.2). While in production point of view, the top five countries in coal production are China (3,700 MT), India (783 MT), the United States of America (640 MT), Indonesia (616 MT) and Australia (550 MT) globally (Fig. 1.3, BP Statistical Review of World Energy 2021). A number of steps have taken to step up coal production, have resulted in continuously upward trend in production touching 226 MT in 1990-91 to 783 MT in 2020-21 for India,

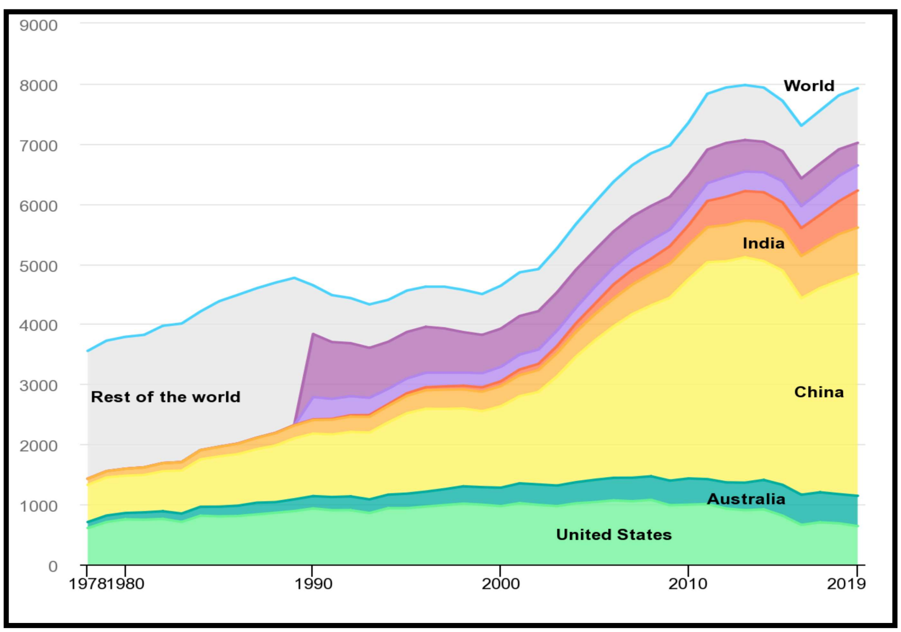

Fig. 1.1: Coal production by countries (in million tonnes) (Source: BP Statistical Review of World Energy, 2020)

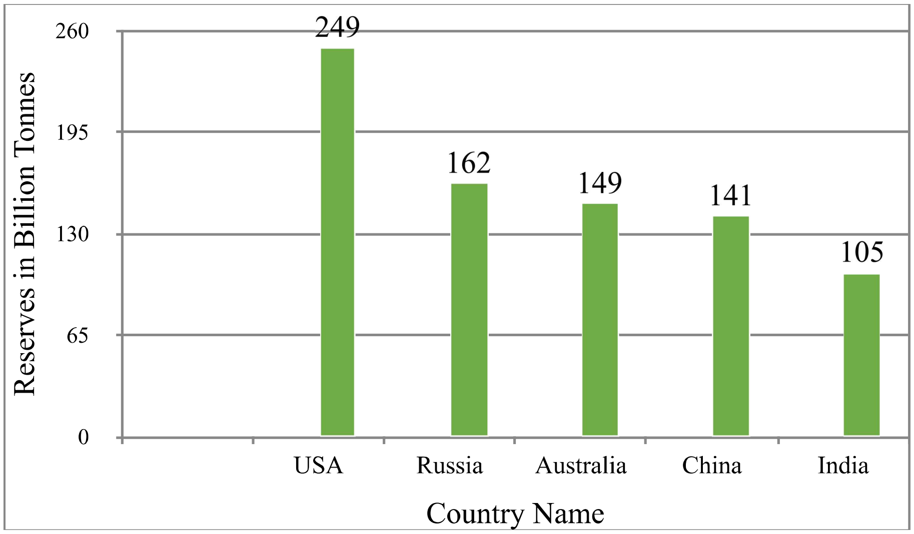

Fig. 1.2: Coal reserves by top five countries globally (Source: US EIA, 2020)

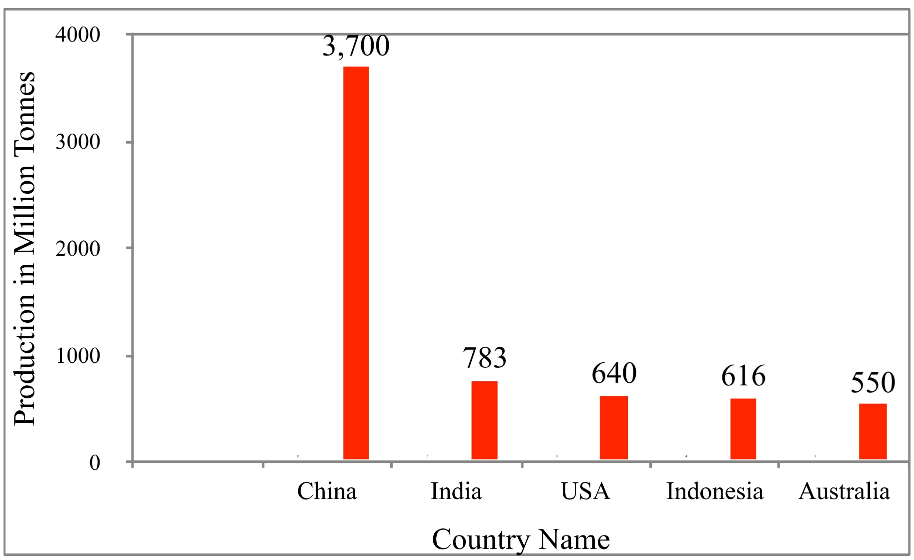

Fig. 1.3: Coal production by top five countries globally (Source: NS Energy, 2021)

against world production of 4,738 MT in 1990 to 8,000 MT in 2020 (IEA 2020). This kind of production and use of coal will lead to a huge generation of coal ash (fly ash and bottom ash) after combustion in thermal power plants.

Coal plays a crucial role in development of India. India has a large quantity of coal. The annual production of coal in India was 783 MT in 2020-21 (BP Statistical

Report 2021). The bulk of coal produced in India is of thermal grade which is approximately more than 671 MT (Ministry of coal 2020-21). The major coal-bearing formation is the Lower Permian Barakar Formation of the Gondwana System (Mukhopadhyay 2018; Dutta 2002).

Rare earth elements (REEs) in coal are an added value and its extraction from coal, may provide additional revenue. The concentrations of REEs in coal are significant, even more than the crustal abundance values (Lin et al. 2017a). Although their presence in the crust is high, their concentration in the form of deposits is low and less common than most minerals (Naumov 2008), thus it is rare to find large enough mineral deposits to make their extraction by conventional mining methods (USGS 2018; Jordens et al. 2013). The experiments at a laboratory scale for the mobility of REEs from coal to leachate have given an encouraging path for the recovery of REEs in coal and its by-products.

1.2 Coal in India

Coal in India has been mined since 1774, and India is the second-largest producer and consumer of coal after China, mined 783 MT in 2020-21. Coal production in India will touch 1000 MT in the year of 2024-25 as per projections in future (Ministry of coal, 2022). Major production of electricity is achieved through coal in thermal power plant, which is around 75% of the total power generation. Coking coal is an essential input for production of iron and steel (Ozbayoglu 2018). Due to high demand and average quality, India imports coking coal (51 MT) to meet the requirements of its steel plants (DGCI&S, 2021). On reserves point of view, India has a vast coal reserves which can sustain up to 100's of years with similar conditions of demand and supply (BP Statistical Review 2021).

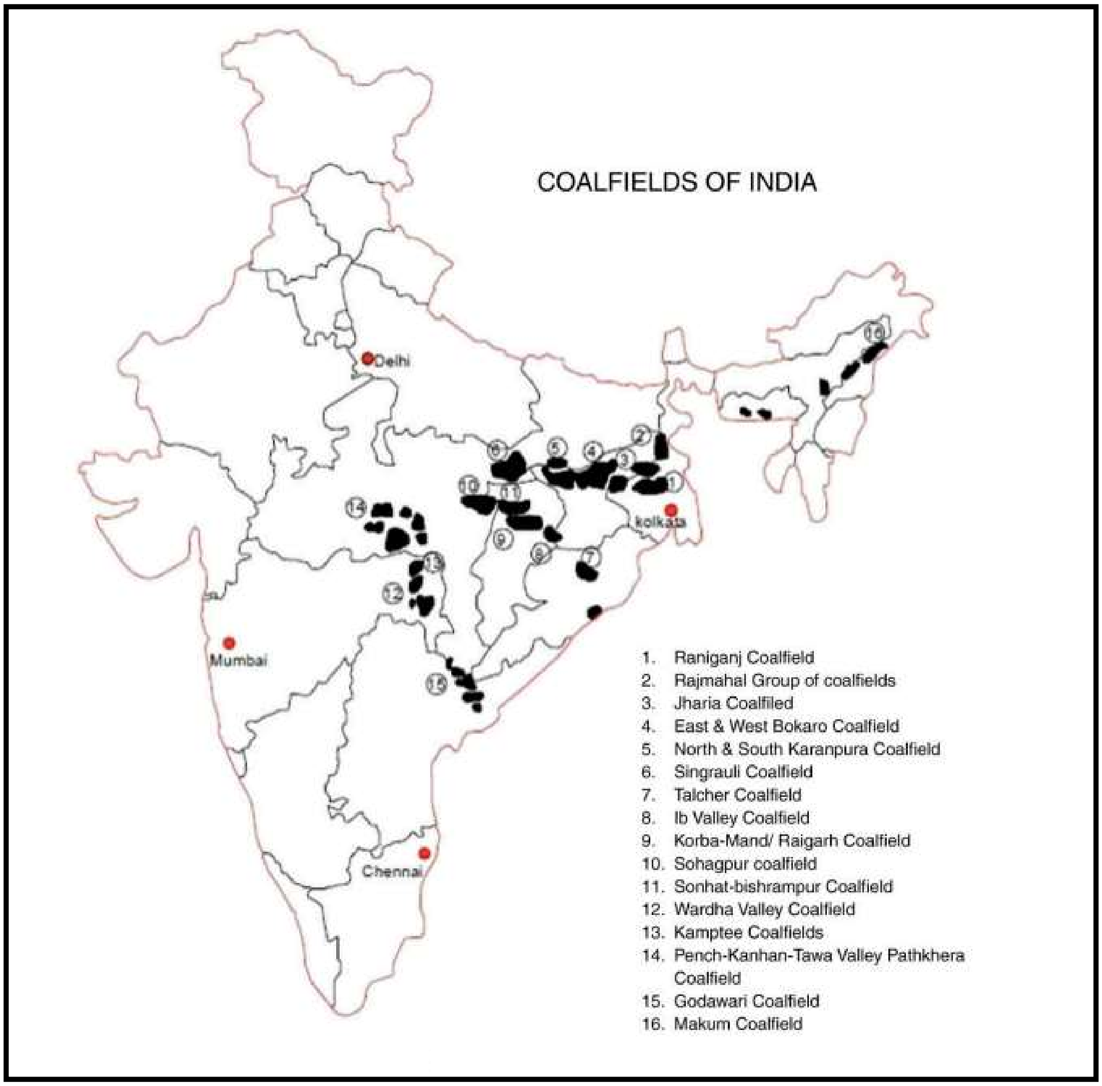

Fig. 1.4: Coalfields of India (Dutta et al., 2011)

There are sixteen major coalfields in India which have the sub-bituminous and bituminous rank of coal (Gondwana coal) as shown in fig. 1.4. It belongs to the Permian system. Lignite or Brown coals are also mined in India, which belongs to the Tertiary system. Tertiary coals of India are reported to be of two categories i.e. sub-bituminous coal and lignite or brown coal (Rajak et al. 2021). Tertiary coal of sub-bituminous type occurs in northeastern India and the main producing states are Assam, Arunachal Pradesh, Nagaland, and Meghalaya as shown in fig. 1.5 (Singh et al. 2010, 2013a). The multiple transgressions on the western plate margin of India nearly 55 ma (Joshi 2007) led to the

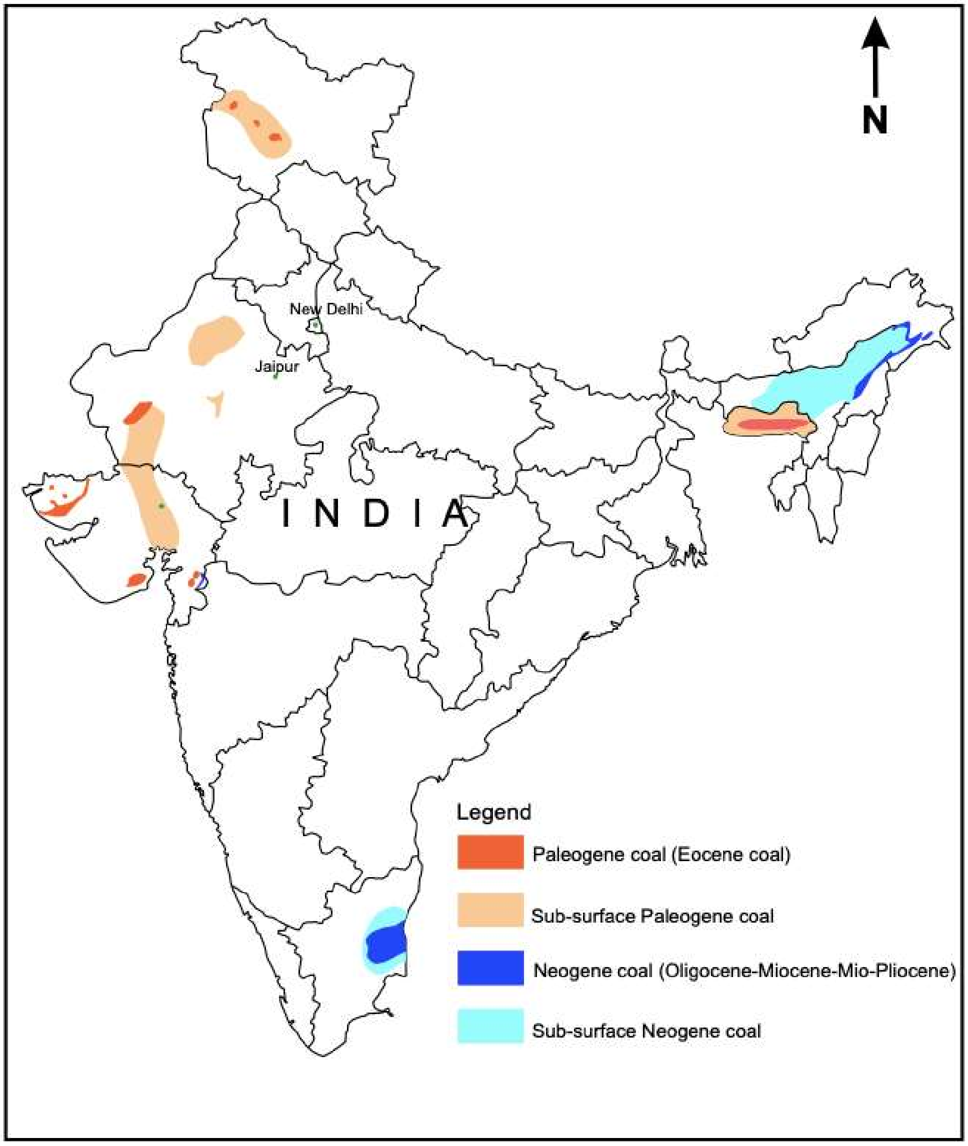

Fig. 1.5: Distribution of Tertiary coal/lignite in India (Rajak et al., 2016)

coal and lignite deposits of Rajasthan, Gujarat, Jammu & Kashmir and Pakistan occur along this plate margin. This type of coal is hardly one percent in our country (Ministry of Coal, GOI 2019-20). Mainly there is huge reserve of Gondwana coals in India.

Based on scientific evidences, Gondwana coals in Indian subcontinent is of allocthonous mode or drift as the principal process of coal seam formation (Sen 1999). Indian coal scientists generally think that the high mineral matter of Lower Gondwana coals was incorporated during the process of transportation of vegetal matter. Because of drift mode of coal formation, the Indian coals have high inorganic content in the form of mineral matter. However, there is wide variation in mineral matter in coal occurring in different parts of the country. The major coal producing districts in India are Dhanbad, Korba, Raniganj, Singrauli, Sohagpur, etc., in which Dhanbad is very important for coal quality, coal production and coal trading (Spencer et al. 2018). Dhanbad (Jharkhand, India), the largest coal-producing city, has been called the coal capital of India. Most of the Indian coals are contained in the Gondwana coalfields (Indian Coal and Lignite Resources, 2017).

1.2.1 Coal production

The total reported production of coal in 2019-20 was 783 million tonnes which was higher by 0.30% in comparison to that of the previous year in India (NS Energy, 2021). Chhattisgarh is the largest coal producing State with a share of about 21.6% followed by Odisha with contribution of 19.6% to the national output. Next in order of share in the total production were Jharkhand (18%), Madhya Pradesh (17.2%), Telangana (8.99%), Maharashtra (7.5%), West Bengal (4.6%) and Uttar Pradesh (2.5%). The remaining 0.21% of coal production was accounted from Assam and Jammu & Kashmir. Coal mining was confined mainly to the public sector which contributed 96% to the national production. The remaining 4% was contributed by the private sector. During the year 2019-20, out of the total production of coal, 7.24% was coking coal and the rest 92.76 was non-coking coal (Indian Minerals Yearbook 2020).

A total of 442 coal mines (as on 31/03/2020) in India reported production in 2019-20. Out of these, Jharkhand accounted for 119 mines while West Bengal 70 mines, Madhya Pradesh 60, Maharashtra and Chhattisgarh 54 each, Telangana 46 and Odisha 29. The remaining mines were from Assam, UT Jammu & Kashmir and Uttar Pradesh.

Coal mining in the country is carried out by both open-cast and underground methods. Opencast mining contributed 94.44% of the total provisional production, whereas the rest of the production (5.56%) came from underground mining during 2019-20.

1.2.2 Coal despatches

Chhattisgarh was the leading State in the despatches in 2019-20 and accounted for 20.8% of the total despatches. The States next in the order were Odisha (19.2%), Jharkhand (18.7%), Madhya Pradesh (15.5%), Telangana (9.1%), Maharashtra (7.1%), Uttar Pradesh (4.8%) and West Bengal (4.7%). The remaining 0.1% despatches were from the state of Assam and Jammu & Kashmir.

Of the total despatches of raw coal effected in 2019-20, a sizeable share of 88.5% was made to the Electricity Sector (power utility and power captive). As much as 1.7% was made to the Steel Industry, 1.5% to the Sponge iron Industry, 1.2% to the Cement Industry, 0.25 % to the Fertilizer Industry, 0.2% to Pulp & Paper Industry and 0.1% to the other basic metals. The remaining 6.5% was made for other priority sectors including Chemical, Textile & Rayons, Bricks and Other (Table 1.1).

1.2.3 Coal reserves

The coal deposits in India primarily are concentrated in the Gondwana sediments occurring mainly in the eastern and central parts of Peninsular India, although Gondwana coal deposits also are found to occur in the north-eastern part of the country mainly in Assam and Sikkim (Table 1.2). The Tertiary coal-bearing sediments are found in Assam, Arunachal Pradesh, Nagaland and Meghalaya (Table 1.3). As a result of exploration

S N	Priority	Amount (In million
1	Power (Utility)	540995
2	Power	85154
3	Steel	11908
4	Cement	8569
5	Sponge Iron	10529
6	Fertilizer	1764
7	Paper & Pulp	1326
8	Other Basic	603
9	Chemical	209
10	Textiles &	101
11	Bricks	26
12	Others	45992
13	**Total**	**707176**

Table 1.1: Despatches of Raw Coal, 2019-20 (Coal Directory of India 2019-20)

SN	Name of States	Proved coal reserves (In million tonnes)
1	Andhra Pradesh	97.12
2	Bihar	309.53
3	Chhattisgarh	24984.86
4	Jharkhand	49468.59
5	Madhya Pradesh	12597.25
6	Maharashtra	7623.74
7	Odisha	40871.77
8	Telangana	10840.88
9	Uttar Pradesh	884.04
10	West Bengal	15189.25
11	**Total**	**162867.03**

Table 1.2: Geological Resources of Gondwana Coals (Coal Directory of India 2019-20)

S N	Name of States	Proved coal reserves
1	Assam	464.78
2	Arunacha l Pradesh	31.23
3	Meghalay	89.04
4	Nagaland	8.76
5	**Total**	**593.81**

Table 1.3: Geological Resources of Tertiary Coals (Coal Directory of India 2019-20)

S N	Type of coal	Proved coal reserves (In million tonnes)
1	Prime-coking	4667.75
2	Medium-coking	14875.55
3	Blendable/Semi-coking	519.44
4	Non-coking	143398.10
5	**Total**	**163460.84**

Table 1.4: Geological Resources of different type of coals (Coal Directory of India 2019-20)

carried out by GSI, CMPDI and other agencies, about 344.021 billion tonnes (including that estimated in Sikkim) of geological coal resources up to 1,200 m depth have been established in the country as on 01/04/2020. Out of these resources, 163.46 billion tonnes are Proved resources. Of the total resources, the share of prime-coking coal is 4.66 billion tonnes, medium-coking & blendable/semi-coking is 15.39 billion tonnes and non-coking coal, including high sulphur (tertiary) 143 billion tonnes (Table 1.4). There is a growing attention for valuable elements in secondary resources. Due to which, coal is considered to be a promising resource for REEs concentration (Hower et al. 2021).

1.3 Rare Earth Elements (REEs)

REEs is a group of 15 elements which we call the lanthanide elements (atomic numbers 57-71), and two transition metal elements, i.e., yttrium and scandium. Promethium (atomic number 61) is extremely rare and is generally considered not to exist in nature. Increasing applications for REEs started in the 1960s when developments in process technology allowed their purification at the commercial scale. The increasing demand for advanced technology development has elevated, and to fulfill this demand, we should

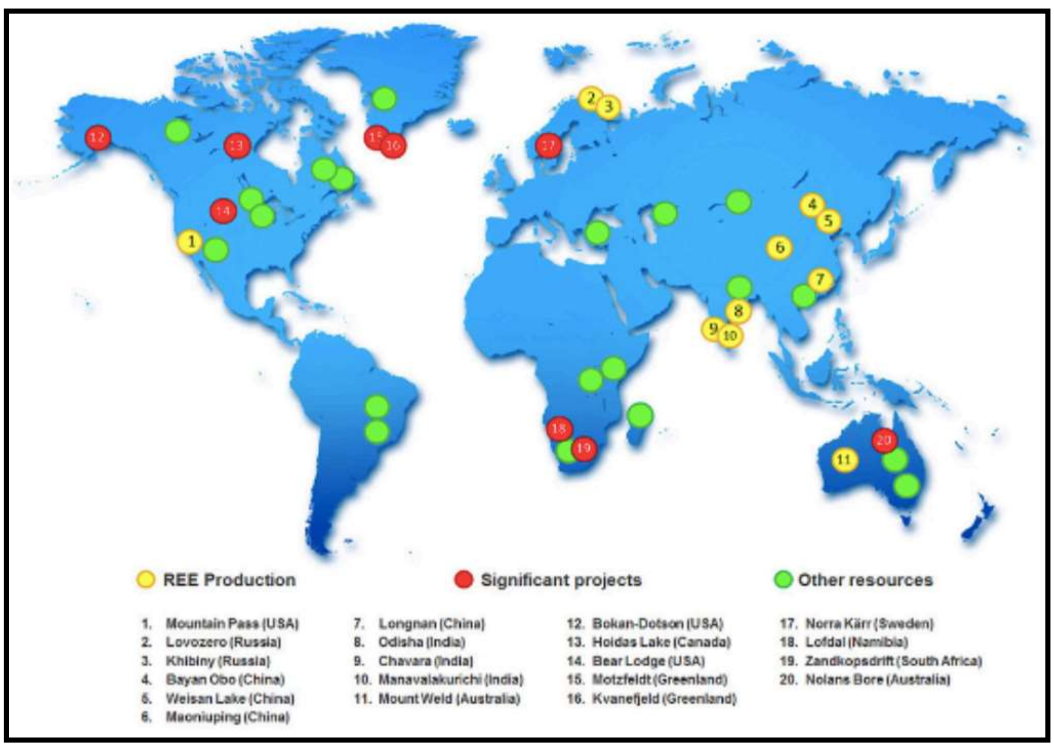

Fig. 1.6: Map showing the global distribution of REE deposits and mines (Barakos et al., 2016)

look for a new resource base substance having REEs (Gaustad et al. 2021). Several deposits of REEs occurred and mined in globally (Fig. 1.6). Because of its geochemical properties, REEs are typically dispersed. It means they are not often found in enough concentrated clusters to make them viable to mine (Kumari et al. 2015). The scarcity of these minerals led to them being called rare earth elements. The existence of REEs in coal is in a new fancy study over the past decade (Kolker et al. 2019). Despite its (REEs) importance, very few studies have been carried out on methods to recover and refine the REEs in coal and its existence.

Rare earth elements include the elements lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). Promethium (Pm) is only found as a by-product of the nuclear fission of uranium. It is not found in nature. Yttrium (Y) and scandium (Sc) are also included in this due to their similarity with the lanthanide series elements (Binningham and Horovitz 1999). Although yttrium has a lower atomic weight, because of its chemical and physical similarities (ionic radius and charge are similar to Ho), it is commonly grouped with the heavy rare earth elements (HREEs) and when included, they are referred to as rare earth elements and yttrium (REY) (Bau 1996; Dai, Graham and Ward 2016; Seredin and Dai 2012). The vital controls of REEs on geological and cosmo-chemical behavior are their size, i.e., ionic radius, redox potential, coordination number, volatile and ionic behavior (Dai et al. 2016b).

These REEs are valued for their distinctive magnetic, phosphorescent and catalytic properties in various products and processing such as high-strength magnets, metal alloys, polishing, catalysts, phosphorous, glass, ceramics and others (Rozelle et al.

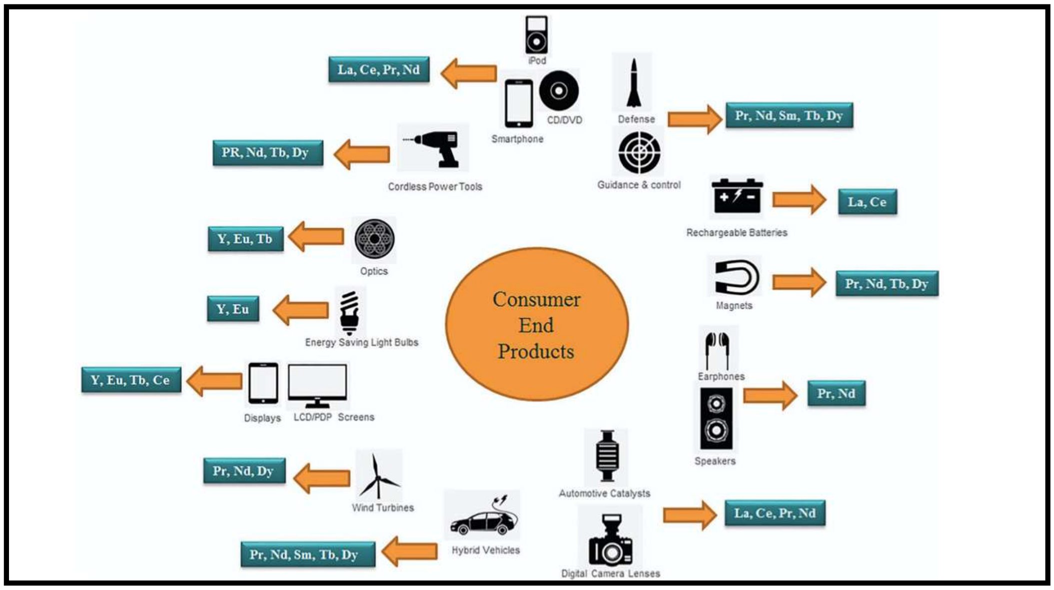

Fig. 1.7: Application of REEs (Report CWR, 2016; Dev S, et al., 2020; Peiravi, M. 2020)

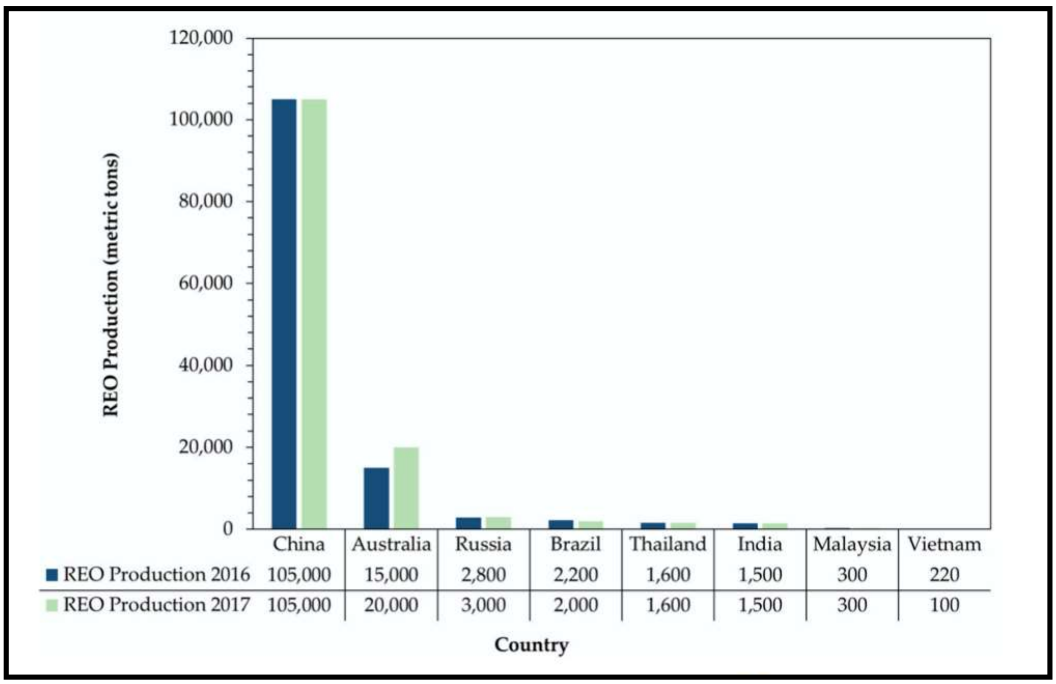

Fig. 1.8: Global productions of rare earth elements (Palacios et al., 2019)

2016; Baron 2020). These elements are also valuable for strategically strengthening the country because they are used for defense in making satellite communications, guidance systems, aircraft structures, fly-by-wire and smart missiles (Fig. 1.7). Due to their economic importance and supply risk, the United States (Bauer et al. 2010) and the European Union (European Commission, 2020) classify REEs as critical materials.

China is leading in REEs production (Fig. 1.8). China accounts for over 95 percent of the world's production of REEs. Therefore, having control of these elements put China at a powerful position. China has limited exports and only allows 39,800 tons (less than 10% of the total) (Gaustad et al. 2021). These REEs are meeting the requirement of electronic industries in China for many companies such as Hitachi, Samsung, and Apple (Palacios et al. 2019). However, there may be scarcity of these elements if a new resource has not been investigated. This international scenario has motivated to search for assured resources of REEs are available in India. India has about six percent of global REE reserves and produces only one percent of global supply (Tripathi 2021). Due to this, it need to be explored other resources (secondary resources) to fulfill the demand.

Coal ash is the material produced after burning (combustion), mainly in coal-fired power plants, including fly ash and bottom ash. Coal combustion by-products (CCPs), also known as coal ash, are a significant industrial waste having adverse impacts on the surrounding environment and human health because of its abundance and potential to free toxic elements by natural leaching at the dumping/disposal sites in mines (Izidoro et al. 2018). However, coal ash may be a promising resource and may be economically viable for the extraction of critical elements such as Ge, Ga, rare earth elements and Y (REE + Y or REY), Nb, Zr, V, Re, Au, Ag, and base metals such as Al (Seredin and Dai 2012; Dai and Finkelman 2018; Dai et al. 2018). An alternative source for REY globally was triggered by a short-lived supply crisis in 2010 and the REY price spike in 2011 (Alonso et al. 2012; Massari and Ruberti 2013; Dai et al. 2018). It led to the investigation of

Elements	Chinese coal[1]		US coal[2]		World coal		
	Av.	No.	Av.	No.	Ra.[3]	Av.[4]	No.[4]
La	18	110	12	6235	1-40	11	10
Ce	35	110	21	5525	2-70	23	11.5
Pr	3.8	110	2.4	1533	1-10	3.5	ND
Nd	15	110	9.5	4749	3-30	12	4.7
Sm	3	110	1.7	5151	0.5-6	2	1.6
Eu	0.65	110	0.4	5268	0.1-2	0.47	0.7
Gd	3.4	110	1.8	2376	0.4-4	2.7	ND
Tb	0.52	110	0.3	5024	0.1-1	0.32	0.3
Dy	3.1	110	1.9	1510	0.5-4	2.1	ND
Ho	0.73	110	0.35	1130	0.1-2	0.54	ND
Er	2.1	110	1.0	1792	0.5-3	0.93	ND
Tm	0.34	110	0.15	365	ND	0.31	ND
Yb	2	110	0.95	7522	0.3-3	1	0.5
Y	9	110	8.5	7897	2-50	8.4	15
Sc	4	110	4.2	7808	1-10	3.9	5
Lu	0.32	110	0.14	5008	ND	0.20	0.07
LREE	78.85	—	48.8	—		54.67	34.70
HREE	22.11	—	17.49	—		17.7	24.75
Total	100.96		66.29			72.37	59.45

Table 1.5: Distribution of REEs concentration in Chinese coal, US coal, and World coal
Note. Values are in parts per million; Av = the average concentration; ND = number of samples; Ra = the range of concentration.
[1]From Tang and Huang (2004). [2]From Finkelman (1994). [3]From Reg et.al. [4]From Ketris and Yudovich (2009).

sources of REY increased significantly. Conventionally, REEs are commercially extracted from rare earth deposits containing REE-bearing minerals such as bastnaesite, monazite, and xenotime, among others (Haxel et al. 2002; Jordens et al. 2013). However, limited supply and increasing demand for REEs are leading to explore alternative or non-traditional resources in coal and coal by-products.

1.4 Global distribution of REEs in coal

Rare earth elements (REEs) occur in coal as trace elements, generally having a concentration below 0.1%. REEs are important constituents for electronic industries in smartphone, lighting, batteries, electric vehicles, electromagnetic motors (Rozelle et al. 2016). Demand for REEs has increased many folds but with limited supply. Trade and permitted restrictions have increased concern over the mining availability of REEs as well as economic and environmental issues (Gaustad et al. 2021). It leads to significant interest in recovering REEs from coal and its by-products (Seredin and Dai 2012; Seredin et al. 2013; Hower et al. 2013, 2016a; Dong et al. 2016; Zou et al. 2014; Zhang et al. 2015; U. S. Geological Survey 2020; Vaziri et al. 2020). There are many publications, investigating the concentration, distribution, mode of occurrence, and origin of REEs in coal (Birk and White 1991; Seredin 1996; Wenhui et al. 2000; Schatzel and Stewart 2003; Wenfeng et al. 2003; Dai et al. 2006; Zheng et al. 2007; Wang et al. 2008; Sun et al. 2010; Liu et al. 2014; Wang et al. 2014; Dai et al. 2016; Hower et al. 2016b; Lin et al. 2017; Arbuzov et al. 2018). REEs distribution in coal of USA and China is given in table 1.5. The average concentration of REEs of the world is also shown in this table. Information on the modes of occurrence of REEs in coal is useful and helps to assess the potential extraction procedures from coal and its by-products (Finkelman 1993; Seredin and Dai 2012; Seredin et al. 2013; Sun et al. 2016; Dai and Finkelman 2018; Finkelman et al. 2018). Generally, in coals, REEs are associated with clay minerals, silicates, feldspars, oxy-hydroxides, phosphates, sulphates, sulphides and carbonate minerals (Franus et al. 2015). However, there are very limited publications describing the REEs' concentrations, distributions and modes of occurrence in Indian coal, though India has a huge coal deposits and is now the world's second largest producer of coal after China (IEA, 2018; Mishra et al. 2019). There is enrichment of rare earth and other elements in fly ash after combustion of coal. The generation of fly ash is also in large volume in India which is more than 200 MT in power plants (Ministry of Power, GOI 2020).

The burning of coal is a threat to the environment because coal releases many heavy metals and toxic elements such as nickel, lead, mercury, antimony, cadmium, and arsenic along with radioisotopes (strontium and thorium) due to burning (Shan et al. 2019). Few heavy metals (Iron, cobalt, copper, manganese, molybdenum, and zinc) are required for health in the form of trace elements, but excess of it in the human body can cause severe or incurable toxicity (Jaishankar et al. 2014). Some trace elements (lead, mercury, arsenic, etc.) also cause various environmental issues to surrounding habitat.

Pyrite present in coal leads to acidic mine water usually forms through dissolution and oxidation process (Sahoo et al. 2014; Zhu et al. 2017a, 2017b). It is a possible way for several elements could be set free by acidic condition (due to more solubility of metals in acidic water) into the water and leads to high concentrations of some elements (cadmium, lead, copper, etc.) as investigated by several researchers (Cravotta 2005, 2015a; Cravotta and Brady 2015b, Johnson 2003; Zhao et al. 2014). Yue and Zhao (2008) stated that zinc, nickel, cobalt and cadmium were released during the dissolution and oxidation of pyrite. The release of many elements such as chromium, lead, aluminium and arsenic were affected by pH of the leachate and absorption and co-precipitation (Yue and Zhao 2008). So, it is necessary to investigate concentration of the toxic elements and their interaction behavior with acidic water.

The increasing environmental awareness about global warming and pressure to zero carbon emission are compelling to assess coal usage for other utilities with reduction in electricity generation (combustion). Hence, in this thesis, an attempt has been made to characterize the coal and also to assess coal as a source of REEs to meet its (REEs) requirement in India. This thesis will also provide an opportunity to recover valuable elements present in coal before its combustion. Hence, in future, the coal may be used as a source for rare earth elements, along with electricity generation in the years to come. Coal may be treated as a secondary source for rare earth elements after primary resources. It will reduce the import of REEs, which are widely used in electronics and other industries.

1.5 Distribution of REEs in Indian coal

A little work has been done knowing the concentration of REEs in Indian coals. However, according Mishra et al. (2019), the distribution of REEs in coal has been studied in Lower Gondwana Coals of the Talchir Coal Basin, India. The concentration of REEs varies 29.6 ppm to 179.4 ppm with an average value of 91.0 ppm. Presence of monazite is also reported in their studies in coals of Lower Gondwana.

1.6 Statement of the problem

The characterization of coal is the basic element for assessing the coal for different uses. For assessing the coal as a source of energy at present, proximate and ultimate analyses are the most common and traditional methods. Presently, bulk production of coal is being used as a source of energy in thermal power plants. Now, the global scenario is changing as for as utilization of coal for energy production is concerned. The decline in coal production is already started by some countries (USA and Australia). Keeping all these issues in mind along with Indian economic condition, a detailed investigation has been made to assess the quality of coal for different utilization along with in power generation. Furthermore, due to international pressure for phasing out and phasing down coal production for combustion, it is also thought to evaluate coal for other purposes rather than the production of power generation only. Further, coal contains many elements and minerals that provide useful information about occurrence and concentration. Now, the mode of occurrence and concentration of elements in coal is being assessed for extraction of valuable elements. A little work has been done so for the recovery of valuable mineral and rare earth elements from coal in India prior to its combustion. The elemental characterization of coal is also need of time to find out the new resources of rare earth elements in coal in our country. At present these rare earth elements are being imported from other countries. The elemental characterization of coal encouraged to conduct a detailed study to evaluate coal as a source of REEs.

1.7 Research Objectives

Keeping the statement of the problem in view, it has been realized that there is a need of detailed study of coal characterization and occurrence of various critical elements in coal. The interrelationship of various parameters of coal characterization is also equally important to understand the coal quality and occurrence of elements in coal. Further, there is a global pressure for no coal combustion for reduction of green house gases and to utilize coal for other purposes such as a source of rare earth elements. The recovery and removal of elements from coal before its combustion may be beneficial economically and environmentally. Hence, the objectives of the present work are as follows:

I. To assess the suitability of coal for different uses (coal characterization).

II. To characterize the coal as a resource of rare earth elements.

III. To assess the possibility of recovery of rare earth elements through leaching of coal

To achieve the above objectives following work has been carried out:

1. Field investigation for knowing the actual geology of the area, coal seam occurrence, coal sampling and collection of field literature and data of the coal mine.
2. Sample preparation for different investigations (geochemical characterization by proximate analysis, ultimate analysis and gross calorific value) and leaching experiments.
3. Mineral identification in coal samples by advance techniques (X-ray diffraction and FTIR).
4. Identification and determination of organic group and nature of bonding in coal samples. Identification of surface morphology along with weight and atomic percentage of elements in coal samples (SEM-EDX).
5. Qualitative and quantitative identification and determination of trace and rare earth elements in coal (ICP-MS).
6. Experiment design and fabrication for leaching at laboratory scale for recovery of rare earth and other elements. Recovery is made by the leaching method with the help of de-ionized water, acidic, and basic solution.

This study will provide a new opportunity to look coal as a source of REEs along with other uses. As mentioned previously, the evaluation of coal and coal by-products as an alternative resource for REEs will be a new research area to meet the requirement of these critical strategic elements for the country. In addition, the geochemistry of coal will further help in understanding the occurrence of REEs. The main contribution of this research is the searching of coal as source of REEs and development of extraction methods for REE from coal that may decrease the dependence on import of these elements.