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Carbon-based raw materials play key roles in technology of the 21st century: Indian case studies

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Review scientific paper

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Abstract

Coal is a vital carbon-based raw material which is used in the production of various advanced nanomaterials. This particularly holds true for the relevant research and development trends in India. New more environmentally friendly processes are under development with respect to metallurgical coke making and quality enhancement of high-ash Indian coal. Compared with chemical and physical methods, beneficiation of high-ash coal and its combustion by-products with organic liquids (various natural oils) are much more superior in terms of costs, efficiency, and environmental implications. Nanodiamonds have emerged as a key platform for nanoscience and nanotechnology developments. Indian scientists have applied eco-friendly and cost-effective ultrasonic assisted wet-chemical method to low-quality NE Indian coal and the resulting nanodiamond particles could have a wide range of applications in the field of microelectronics, optoelectronics, and biosensing. Also, Indian scientists have been working on ultrasonic-assisted chemical synthesis of activated carbon from low-quality subbituminous coal and its preliminary evaluation towards supercapacitor applications. This article shows that coal is a versatile and valuable raw material which should be saved for future generations at all costs.

Keywords:
carbon; Indian high-ash coal; nanomaterials; supercapacitor; coal beneficiation

1. Introduction

Carbon is one of the most important and interesting natural elements due to its versatile applicability in advanced nanomaterials, such as nanodiamonds, fullerenes, carbon nanotubes, graphene, nanofibers, nanoporous activated carbon, etc. Recently, these have attracted tremendous investments, and research and development efforts as they can be designed, and tailor-made at molecular levels in order to acquire the desired functionalities and properties. Their nanometer scale is offering countless possibilities for novel materials, devices, and systems that could serve humankind (**Reddy et al., 2009**). These novel materials are characterized by different chemical and physical properties resulting from the structural geometry of the atoms and the type of chemical bonds within the molecules. The continuously increased commercial uses of engineered carbon-based nanomaterials include technical, medical, environmental, and agricultural applications (**Zaytseva & Neumann, 2016**). Coal can be an abundant and cheap natural precursor utilized for the synthesis of carbon-based nanomaterials (**Moothi et al., 2012**), which can be applied in the energy and environmental sectors.

Nowadays, materials science is directly impacted by a growing global population and climate change, while the latter has often been related to coal. Hence, worldwide research on today's coal use (or fossil fuels in general) is mainly focused on clean energy and innovation and the pathways toward achieving a net zero future. To curb global warming below 2°C or 1.5°C, a transition to net-zero-emissions energy systems by 2050 is urgently needed. From a climate change point of view, the ongoing situation seems quite challenging as the International Energy Agency has warned that it is unlikely that the world will meet its 2050 net zero carbon climate goals without a major acceleration in clean energy innovation. Out of more than 400 clean energy technologies, the four most critical ones that need innovation are battery technologies, carbon capture and storage, bioenergy, and low-carbon hydrogen; they are currently mostly in the development phase and/or costly (**Loughran, 2020**). In a comprehensive review by **Li et al.** (**2022**), twelve-years of quantitative and qualitative data were collected to examine if British Petroleum, Chevron, ExxonMobil, and Shell were decarbonizing and shifting from fossil fuels to clean energy. The authors examined behaviour

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from three perspectives: (1) discourse: frequency of climate- and clean-energy-related keyword use in annual reports; (2) strategies: pledges and actions related to decarbonization and clean energy and (3) investments: production, expenditures, and earnings for fossil fuels as well as investments in clean energy. The key findings of their work show the mismatch between discourse, pledges, actions and investments, and the authors conclude that none of the four giants are currently on the way to a clean energy transition. Essentially, the study observed increasing tendencies toward strategies related to decarbonization and clean energy, but dominantly by pledges rather than concrete actions.

Coal is, undoubtedly, an invaluable material that has multiple prospective uses. Primarily, it is a fuel that has a large share (60%) in global electricity generation in the 21st century, despite the worldwide concerns over global climate change. It is also used in manufacturing of steel, cement, and liquid fuels. China, USA, India, Russia, and Japan are the five largest coal users, accounting for 76% of total global coal use (**WCA, 2013**). The fact that coal reserves are immense implies that it could significantly contribute to the world's energy and chemical markets for a long time, probably centuries (**Schobert & Song, 2002**). Recent years have witnessed a growing interest in coal as a primary source of organic chemical feedstocks. Thousands of different products are made from coal or coal by-products, such as soaps, dyes, solvents, aspirins, plastics, and fibres, etc. By means of the three processes, carbonisation, gasification followed by conversions of the synthesis gas (syngas) and liquefaction/hydrogenation, coal gets converted to chemicals and materials that are profitable, important, and versatile products. Specialty carbon materials, characterised by their innovative aspects, include graphite, fullerene, and diamonds. Fine chemicals, products in the chemical industry that are manufactured in small quantities but in a large variety for greater added value than those that are mass produced, include pharmaceuticals, agricultural chemicals, products for electronic applications, paints and coatings, dyes and other colourants, adhesives, synthetic detergents, and cosmetics (**Nalbandian, 2014**). A comprehensive review by **Schobert & Song** (**2002**) gives a list of carbon-based materials from coal and coal-derived liquids (see **Table 1**). The authors emphasize the importance of alternative uses of coal (and oil as well), and that society should appreciate the unique features and advantages of coal and make use of them in a most effective, efficient, and responsible way. Climate change is certainly shifting the dominant role of coal in the power sector to one which is converting it to chemicals and innovative carbon materials. The authors conclude that saving coal for future generations should be of paramount importance.

India's energy system has been dominated by coal for decades. Despite the leading role of India in solar energy, coal's share in India's energy mix rose from 40% in 2010 to 44% in 2019, and coal continues to be the single largest fuel in this mix. India is the fourth-largest global energy consumer today, after China, the United States, and the European Union. Coal accounts for half of the energy produced in India today, and coal supply and end use attract a third of the total annual energy investment. India's share in the growth in renewable energy is the second largest in the world, after China. India is heavily abundant in terms of solar photovoltaics (PV), with similar holds for battery storage. By 2040, India's power system is expected to surpass the European Union and is the world's third largest in terms of electricity generation; it also has 30% more installed renewable capacity than the United States. India is expected to become a major market for clean energy technologies. The government supports local production, using the leverage that India is a leader in the implementation of battery storage and other clean energy technologies and as a country with a large and growing domestic market (**IEA, 2021**). Due to high recoverable reserves of coal in India, its potential of producing countless coal-derived chemicals is huge, given that coal is a hydrocarbon resource required for petrochemical production (**Nexant, 2010**). Such substances have become increasingly interesting items in terms of research and development, with respect to future non-fuel utilisation of coal.

Table 1: List of carbon-based materials from coal and coal-derived liquids (**Schobert & Song, 2002**)

Materials from coal	Materials from coal-derived liquids
Metallurgical cokes	Pitch-based carbon fibres
Activated carbon adsorbents	Mesocarbon microbeads
Molecular sieving carbons	Carbon electrodes
Graphite and graphite-based materials	Carbon fibre reinforced plastic
Composite materials (coal/polymer, etc.)	Activated carbon fibres
Fullerenes	Mesophase-based carbon fibres
Carbon nanotubes	Carbon whiskers or filament
Diamond-like films	Binder pitch
Intercalation materials	Humic acid derivatives

According to a report (**Mills, 2011**), roughly half of the world's estimated recoverable coal reserves are comprised of low quality coals, predominantly lignites, subbituminous coals, and high-ash bituminous coals. Although their use is coupled with many drawbacks, many parts of the world heavily rely on the greater use of low ranking and low-quality coals, mainly due to economic reasons. A low-quality coal has a limited use in the power sector because of one or more following properties: low heating value, high moisture content, low volatile matter content, high ash content, high sulphur content, low ash fusibility, high alkaline content, and high milling power consumption. India is among many coal-producing countries that have experienced the exhaustion of good quality and/or easily accessible reserves, which has resulted in increasing reliance on lower quality coal deposits. Although Indian coals have always had high ash contents, domestic coal quality has shown a steady decline, which has reduced the overall efficiency and created difficulties in many coal-fired power plants across India (**Meshram et al., 2015**). Power generation is the biggest coal-consuming sector, with coal-fired power plants generating ~70% of India's electricity. The worldwide trend of trading and marketing low quality coal is expected to continue growing for the foreseeable future. It is facilitated by the ongoing development of various novel drying, cleaning and briquetting techniques aimed at upgrading different low grade and low rank coals in order to improve their properties and increase their value (**Mills, 2011; Sabar et al., 2019**). The aim of this mini review is to present two classes of relevant research, with an emphasis on Indian case studies as follows: 1/ utilization and improvement of high-ash coal and its useful by-products from an environmental point of view, and 2/ development of novel carbon-based materials that can be utilized in various ways in the domains of the industry, technology, and energy sectors.

2. Beneficiation of high-ash coal and its combustion by-products with organic liquids

Thanks to complex and very variable chemical (molecular) and physical (conformational) properties of coal, conducting a detailed structural characterization of coal is extremely difficult, yet motivational still today (**Hower et al., 2007**). A petrographic analysis of coal can reveal its thermoplastic properties that are significantly important in the coal industry (**Sahoo et al., 2019**). Upon heating (carbonization) coal undergoes chemical and physical (softening, melting, fusing, and re-solidifying) changes. By means of FT-IR spectroscopy, it is possible to determine molecular structure, especially the functionalities of organic compounds in coal structure and the structural changes taking place during coalification (**Saikia et al., 2007**). Hereby, **Chakravarty et al.** (**2020**) carried out a comparative study on three Indian coals having different ranks (different chemical structure and petrography) as follows: coking coal, semi-coking coal, and non-coking coal. By using FT-IR spectroscopy and the free-swelling index, it was found that the three coals were different with respect to their structural features, and that rank had a major role in caking properties and organic structure as well. Also, the authors note that coal rank was not directly proportional to the caking properties of coals. A paper by **Chakladar et al.** (**2020a**) deals with heat affected coal resulting from magmatic (igneous) intrusions into coal beds, which is a common phenomenon. These occurrences induce geochemical and petrographic alterations in coal, such as changes in vitrinite reflectance, petrographic composition, optical texture, mineralogy, and bulk geochemistry. Igneous intrusions affect both organic and inorganic constituents in coal (**Dai & Ren, 2007**; **Finkelman et al., 1998**). These intrusions substantially limit the utility of such coals in power and steel-making sectors, which is a serious issue in India. Furthermore, the demineralization (eliminating the ash content from coal) potential of heat affected coals is low, and it largely depends on the surface chemistry of coal molecules. Literature on the possible ways to beneficiate such chemically altered semi cokes is scarce. Commonly, the high-ash low-grade coals of Indian origin are challenging to demineralize due to their unfavourable hydrophilic surface chemistry. **Chakladar et al.** (**2020a**) conducted a beneficiation technique by coupling the ultra-fine (9–10 μm) grinding with oil (10 vol% sunflower oil under acidic conditions, pH 2–3) agglomeration, which resulted in a significant reduction of ash content of heat altered coals. The final ash content of the resultant coal was found to be approximately 10%, which was equal to the ash removal rate of up to 60% compared with the precursor coal (28% ash). Such an efficient demineralization of heat altered coals should open new avenues towards their utilization in industry, otherwise rendered useless. Similarly, turpentine oil was found to be efficient (only 10 vol. %) for coal demineralization purposes, which was presented in a paper by **Chakladar et al.** (**2020b**). According to the authors, chemical structural resemblance between the primary components of turpentine oil and the predominant π-delocalized aromatic structure of high rank coals could be the reason behind the improved adsorption of oil. Herewith, an easily dried natural oil which is cheap and readily available has a huge applicative potential in a demanding commercial process like coal beneficiation. The removal of ash was up to 50%. **Chakladar et al.** (**2021a**) report for the first time that castor oil, being non-edible, biobased, non-toxic, and non-polluting in nature, proved to have a substantial demineralization potential suitable for high-ash Indian coals. Mineral removal was up to 60%, and the authors speculate that the chemistry between ricinoleic acid in castor oil with that of surface functionality of coal might be the reason behind the obtained agglomeration results. Noteworthy, oil must be cost-effective, abundant, and efficient in agglomerating at lower concentrations. One such oil is native in India and is called Mahua, which is a tree borne oilseed. Mahua is a deciduous tree that grows widely under dry tropical and subtropical climatic conditions. Low grade coal from Kaniha (Odisha, India), containing 35% ash was treated by Mahua oil, and demineralization potential was up to 45–50% at lower oil concentrations (10–15 wt.%), devoid of surfactants (**Chakladar et al., 2021b**).

Coal ash often contains valuable rare earth elements (REEs) that could be extracted from it. REEs have strategic importance due to numerous applications in various high-tech products, such as cell phones, flat-screen TVs, electric cars, wind turbines, satellites, defence aircrafts and magnets. They are increasingly recovered from coal ash recently (**Wang et al., 2019**). From an environmental point of view, the extraction of REEs from ash using mineral acids should be avoided because of their corrosive hazardous characteristics. They are highly disadvantageous from technical aspects as well. Therefore, **Banerjee et al.** (**2021**) report for the first time REE extraction potential of organic acids, primarily by a single step process. The authors conducted a systematic study on leaching behaviour of different organic acids (succinic, lactic, tartaric, malonic, and citric acid) with varying pKa. They investigated the effect of process parameters as follows: acid type, acid concentration, temperature, pulp density and leaching duration. According to findings, the best leaching efficiency (65% for LREE, 19% for HREE & 62% for total REE) was achieved using 5% tartaric acid solution having natural solution pH 1.8 at 90°C, and the leaching duration was 60 min. Contrary to mineral acids, carboxylic acids leached out REEs without damaging minerals in coal ash, thus providing the opportunity to utilize the treated coal ash for other applications like in the cement and brick industries.

3. Novel carbon-based nanomaterials

In India, among 4-5 major coal mining regions, one is situated in the NE Assam and Meghalaya states. There, low-grade coal has high levels of sulphur (2−8%), the content of which is mainly (75−90%) organically bound, while the rest is in inorganic forms (sulfate and pyritic sulfur). **Das & Saikia (2017)** demonstrated how that coal could be used as cheap feedstock for the fabrication of carbon nanomaterials. They used the ultrasonic assisted wet-chemical method in the presence of H_2O_2. The nanodiamond particles showed stable and bright blue fluorescence, which could be specifically applied in bioimaging engineering, photovoltaics, and optoelectronics. The authors (and references therein) elaborate versatile applicability of nanodiamonds, for example in novel wear-resistant polymers, metal coatings, and lubricant additives due to their superhardness, exceptional chemical resistivity, and abrasive nature, respectively. Also, nanodiamonds have been widely used in biomedical imaging, drug delivery, and other areas of medicine. Furthermore, nanodiamonds were produced from hazardous carbonaceous atmospheric aerosols by using ultrasonic assisted oxidative chemical technique presented in paper by **Islam et al. (2019)**. They were found to be non-toxic and bio-compatible, thus suitable for bioimaging purposes. Fluorescent nanodiamonds (FNDs), produced from carbon-based precursors (graphite, coal, coke, etc.), were reviewed by **Boruah & Saikia (2022)** who note that FNDs have a surface embedded with some crystallographic defects containing coloured centres which surmount the properties of other fluorochromes (conversion nanoparticles, quantum dots, nano tubes, fullerenes, organic dyes, silica, etc.). Thanks to their peculiar properties, such as photostability, inherent biocompatibility, outstanding optical and robust mechanical properties, excellent magnetic and electric field sensing potentiality, FNDs are utilized for bio-imaging, delivering drugs, fighting cancer, spinelectronics, imaging of magnetic structure at nanoscale, and as promising nanometric temperature sensors. Carbon quantum dots (CQDs) and graphene nanosheets (GNs) are among the most attractive fluorescent carbon nano-sized materials with unique optical and physico-chemical properties, and are variously applied in chemical sensing, biomedicine, semiconductor devices, and photo- and electrocatalysis. They have been synthesized from cheap and abundant carbon sources, such as coal, petroleum coke, graphite, and coal-based humic acid by facile, cost-effective hydrothermal techniques (**Saikia et al., 2020a**). The authors demonstrate how the value of CQDs and GNs is reflected in their use in the photo-degradation of harmful 2-nitrophenols in polluted water systems. Readers interested in CQDs can refer to a review paper by **Das et al. (2018)**, which demonstrates recent progress in the synthesis, functionalization, and technical applications of CQDs using electrochemical oxidation, combustion/thermal, chemical change, microwave heating, arc-discharge, and laser ablation methods from various natural resources. They note that natural carbon sources are used for the preparation of CQDs owing to their low cost, environmentally friendly characteristics, and natural abundance.

Low-grade coals from NE India have also been efficiently used to produce supercapacitor electrode materials by using wet-chemical methods (**Das et al., 2017**). Supercapacitors are energy storage devices which have received huge attention due to their high-power density, short charging time, and long cycling life. These all play an important role in achieving better fuel economy, thus decreasing harmful emissions, and reducing the reliance on petroleum resources. Thanks to nanotechnology which has offered new frontiers by creating unique inventions and new materials for energy storage, the world market for supercapacitors is growing rapidly. Activated carbons, carbon fibres, onion-like carbons, graphene oxide, carbon nanotubes, carbide-derived carbons, humic acid, and graphene, and their composites, they all are different allotropes and derivatives of carbon that have attracted much attention as promising materials for charge storing. **Das et al. (2017)** demonstrated that abundantly available low-grade Indian coal could be a source of supercapacitor electrode materials, which was confirmed by a multi-analytical approach of characterization consisting of chemical analysis, FT-IR, XRD, XPS, Raman, SEM-EDX, BET, and HR-TEM techniques. The authors showed how the low-cost, facile, and eco-friendly aspects made as-synthesized coal-derived graphene like carbon nanosheets (GCNSs) promising electrode material for supercapacitor application. Future technologies will be based on carbon nanomaterials with promising and excellent chemical, physical, mechanical, and thermal properties. A comprehensive review by **Saikia et al. (2020b)** is focused on different types of natural carbon sources used for the synthesis of graphene and carbon products/derivatives towards the fabrication of supercapacitors with high electrochemical performance. Electrochemical energy storage is considered as the most promising among various renewable energy storage technologies owing to high efficiency, versatility, and flexibility. **Singh & Ojha (2020)** reported for the first time a simple and cost-effective synthesis of water-soluble graphene (micro-sized) by utilizing coal and its electrochemical properties for practical supercapacitor applications. Thanks to superb properties, graphene and its derivatives are used in high performance supercapacitors, batteries, nanoelectronics, composites and sensors. The authors found out that graphene showed a long cycle stability as the value of specific capacitance remained at ~91% after 2000 cycles at the current density of 10 mA/g.

4. Discussion and conclusions

The rise of the global population and the modern, technologically driven lifestyle are coupled with the rising energy demands. Recent geo-political turmoil in the Eastern Europe (war in Ukraine) could revive the coal extraction industry in some EU countries, and that will be very challenging considering the problem of global warming and environmental pollution trends. Countless unregulated landfills containing coal-combustion by-products (ash and slag) already pose hazards for the environment (**Petrović et al., 2022**), while soaring coal-derived CO_2 would threaten the global climate target which limits global warming to well below 2°C compared to pre-industrial levels. However, coal will remain an indispensable domestic source of energy, especially in developing (Asian) countries for many years (**Chen & Mauzerall, 2021**). It is also indispensable in the iron, steel, and cement production industries. Certainly, coal will remain vitally important to the growing Indian economy, being used extensively by both the power sector and major industries. Indian electricity demand has risen sharply in recent years, and during the last decade, production and consumption has increased by ~64%, while the projected rate of increase up to 2020 was the highest in the world (**Mills, 2011**). Considering the world energy crisis, rising prices of crude oil and natural gas, and gradual depletion of high-quality coal reserves, upgrading of low-grade coal (e.g., demineralization and/or desulfurization) into a form that is economically more valuable and environmentally acceptable has been pursued by many researchers.

Meshram et al. (2015) reviewed demineralization/desulfurization of Indian coals containing high ash and/or sulfur by physical, microwave, bio- and chemical beneficiation methods. Chemical beneficiation methods are superior to physical ones, but they use expensive reagents and result in large quantities of wastewater. During chemical leaching processes, major minerals in coal like kaolinite, silica, carbonate, and sulphur bearing minerals are removed from coal by the dissolution in acid or alkali solutions. Effective demineralization depends on the type and amount of mineral constituent present in coal (**Behera et al., 2017**). Therefore, **Meshram et al. (2015)** recommend a combined approach involving physical beneficiation followed by chemical cleaning. **Barma et al. (2018)** point out that although physical or physico-chemical beneficiation processes are simple, economical and easy to operate, they are inefficient and disadvantageous for Indian low-grade coals due to the following: (1) drift nature, (2) poor washability characteristics, (3) presence of chemically bound finely disseminated minerals in the coal matrix, (4) requirement for larger coal particle size (> 0.5 mm) in case of gravity-based beneficiation technique, (5) oxidized nature of coal which impedes its flotability during flotation process, and (6) requirement for small feed size (< 100 μm) in the flotation process which is energy intensive. The authors suggested ultrasonic cleaning as a promising technique that could be an alternative to the conventional physical process. Their ultrasound process attained high demineralization and desulfurization efficiency up to 40% and 50%, respectively. On the contrary, **Saikia et al. (2021)** presented an environmentally friendly processing technology based on the combined effect of ultrasonic and microwave irradiating energy applied to high-sulfur low-quality NE Indian coal. Its novelty is the fact that it requires no drastic chemicals. Within less treatment time, and by using a smaller amount of reagents in comparison to conventional methods, a cleaner coal product is attained, while up to 70% of ash matter is removed from coal. Compared with chemical and physical methods, beneficiation of high-ash coal and its combustion by-products with organic liquids (elaborated in the abovementioned Chapter 2) are much more superior in terms of costs, efficiency, and environmental implications.

The combined effect of increasing the scarcity of raw materials and environmentally sustainable solutions required by customers is driving innovation in materials and design. The stretchability, softness, mechanical strength, and electrical conductivity are remarkable physical and chemical properties of organic (carbon-based) materials, that have gained significant attention from researchers across the world (**Wade & Wood, 2018**). Such properties make them attractive for use as the key components in catalysts, biosensors, fuel cells, batteries, and electronic devices. The main obstacle to their viable production is the high cost of carbon feedstocks (**Hoang et al., 2018**), mostly represented by graphite and hydrocarbons (acetylene, xylene, methane, etc.). However, **Kumar et al. (2016)** report that there are various natural hydrocarbon precursors for the synthesis of carbon-based materials, such as turpentine oil, eucalyptus oil, palm oil, neem oil, sunflower oil, castor oil, biodiesel, tea-tree extract, honey, milk, sugar, butter, egg, etc. Green fabrication of carbon-based nanomaterials by using cost-effective strategy has been in focus of some research laboratories in India recently. Herewith, **Das et al. (2019)** report a novel oxidative chemical method for the synthesis of high-value carbon dots from cheap and abundant low-quality high-sulfur NE Indian coal for use in high-end applications. They used a wet-chemical ultrasonic stimulation-induced process which was environmentally facile and less drastic compared with other relevant methods. The resulting carbon dots proved to be non-toxic, and safe bio-compatible materials for optical-imaging as well as bio-imaging purposes. Furthermore, **Das et al.** (**2016**) detected carbon nano-balls and nano-tubes in clean coal products obtained by molten caustic leaching of low-quality Indian coal, along the removal of the considerable amount of detrimental ash and sulfur. More novel related research is provided in Chapter 3. Finally, a few words about carbon-based supercapacitors that offer high-capacity energy storage and short charging times in battery technology. Now, researchers are trying to identify the perfect nanostructures as the production of graphene still requires harsh chemicals or expensive processes, and there are still enormous quality control challenges (**Wade & Wood, 2018**). An Indian research team (**Bora et al., 2021**) presents an eco-friendly method consisting of ultrasonic-assisted chemical activation to synthesize the activated carbon (AC) with high specific surface area and high porosity from low-quality subbituminous Indian coal. Their preliminary electrochemical evaluation showed that the coal-derived ACs had reasonably good electrochemical properties with a maximum potential window of 2.5 V and more than 1000 cycles, exhibiting a considerable energy density and power density with the possibility of making low-cost supercapacitors for use in small/general electronics. Moreover, the authors emphasize that the reported ultrasonic-assisted chemical activation method was more effective than other activation methods to synthesize the ACs from abundant low-grade coal resources on a large scale.

In conclusion, it can be said that coal, as an invaluable material, has multiple prospective uses. Apart from the power sector, its non-fuel use will be largely employed by future nanotechnologies and clean energy sectors. Coal ash is increasingly perceived as a resource of valuable trace elements that should be extracted by using mild, environmentally friendly liquids. Coal was a dirty fossil fuel back in the past. However, clean coal technologies have promising perspectives, and coal as a versatile and valuable raw material should be saved for future generations at all costs.

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SAŽETAK

Ključna uloga sirovina na bazi ugljika u tehnologiji 21. stoljeća: indijska iskustva

Ugljen je vitalna sirovina na bazi ugljika koja se koristi u proizvodnji raznih naprednih nanomaterijala. To posebno vrijedi za relevantne trendove istraživanja i razvoja u Indiji. U razvoju su novi ekološki prihvatljiviji procesi za proizvodnju metalurškoga koksa i poboljšanje kvalitete indijskoga ugljena s visokim pepelom. U usporedbi s kemijskim i fizičkim metodama, obogaćivanje ugljena s visokim sadržajem pepela i nusproizvoda njegova izgaranja organskim tekućinama (razna prirodna ulja) mnogo je superiornije u smislu troškova, učinkovitosti i ekoloških implikacija. Nanodijamanti su se pojavili kao ključna platforma za razvoj nanoznanosti i nanotehnologije. Indijski znanstvenici primijenili su ekološki prihvatljivu i isplativu ultrazvučno potpomognutu mokru kemijsku metodu na nekvalitetni indijski ugljen, a dobivene čestice nanodijamanta mogle bi imati širok raspon primjena u području mikroelektronike, optoelektronike i biosenzora. Također, indijski znanstvenici rade na ultrazvučnoj kemijskoj sintezi aktivnoga ugljena iz subbituminoznoga ugljena niske kvalitete i njegovoj preliminarnoj procjeni u svrhe superkondenzatora. Ovaj članak pokazuje da je ugljen svestrana i vrijedna sirovina koju pod svaku cijenu treba čuvati za buduće generacije.

Ključne riječi:
ugljik, indijski ugljen bogat pepelom, nanomaterijali, superkondenzator, poboljšanje ugljena

Author's contribution

Željka Fiket (Ph.D., senior scientist, REE geochemistry) assisted with REEs themes. **Binoy K. Saikia** (Ph.D., principal scientist, coal chemistry) assisted with nanomaterial topics. **Sanchita Chakravarty** (Ph.D., chief scientist, coal chemistry) assisted with the coal beneficiation topic. **Gordana Medunić,** (Ph.D., full professor, environmental geochemistry) performed writing-review and editing.