Chapter 5
Enhancing Biomass Production and Utilization for Sustainable Energy in India

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Abstract All efforts are being made to achieve the targets of reaching Net Zero at the earliest. India also is doing its optimum in eliminating the consumption of fossil fuels and maximizes the development of new and renewable sources. Biomass energy including those from agricultural residues has vast potential of its exploitation in a regulated form. The country today is facing the devastating problem of farm and forest fires for want of a foolproof strategy to contain the same. The enormous phytomass generated by the invasive water hyacinth and other aquatic and land weeds need to be harnessed through preparation of energy bricks that could be used in time of need. Cow and buffalo dung cakes are now being utilized on a large scale for cremation in rural areas. This is being done by digging pits under a closed system that saves on energy consumption that could be avoided through a proper planning. Scientific studies on containing stubble burning in the developed states like Punjab, Haryana, and western Uttar Pradesh are likely to help tackle this problem that crops up every year during the start of winter. National Capital Region bears the brunt at its worst. Carving of energy bricks from *Pinus* needles in the hilly states needs to be geared up on an enhanced scale. This chapter reviews the status of biomass production in India and takes into account the possibilities of their scientific harnessing on an improved scale to provide clean energy solutions in the country.

Keywords Biomass · Plants · Aquatic · Laticiferous · Invasive · Weeds · Biofuel · Bioenergy

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5.1 Introduction

The world today is suffering from a number of health problems caused by the all-pervading air pollution and could ill afford the luxury of using fossil fuels any longer for a sustainable life on the planet. It is high time all forms of clean energy, most of them now christened as new and renewable forms of energy, were adopted at a rapid pace. The example could be cited of the Indian Railways that is on the way to fast electrification. Cars, buses, trains, and aeroplanes run on electricity are now becoming a day-to-day affair. It is expected that share of petrol–diesel cars will come down to less than 50% in the coming 4 years. By 2027 every second car will be an electric one. Auto companies are reducing the cost of electric cars under competitive market strategies. Mid-sized cities in India have emerged as big demand centres for EVs. The annual growth rates of high speed electric two-wheeler sales in tier 2 and tier 3 cities have surpassed those in tier 1 cities.

The summer of 2024 witnessed the worst ever heat wave caused by the adverse effect of greenhouse gases released on account of fossil fuels. As against the previous records of heat wave of about 10 days, the year 2024 witnessed its extension by another 10 days. Coupled with a higher humidity level the overall heat index made the situation unbearable. The difference in the night and day temperatures also minimized. It is under such a situation that production and utilization of clean energy has become extremely essential. The UNFCCC has been striving hard to reach the target of net zero carbon emission by 2050. India, however, keeping in view its ground realities of being a developing country, has initiated all possible steps to achieve this target by 2070. India is making all strides to move ahead in the field of new and renewable energy forms including solar, wind, hydro, hydrogen, biomass, etc. India has taken a lead in the formation of Global Solar Alliance. India declared during 26th Conference of Parties held at Glasgow in 2021 its goal to become a net zero economy by 2070. It has now initiated steps in the desired direction. India intends to become a developed economy by 2047. To achieve this target, by 2030, India is likely to produce 500 GW of non-fossil energy by projecting carbon emission reduction by 1 billion tons. Carbon intensity of GDP is likely to be reduced by 45% from 2005 levels. By raising more forest and tree cover, India shall be in a position to create 2.5–3 billion tons of additional sink.

Time is now ripe to harness the vast potentials of biomass energy ingrained in the sea weeds including those of marine algae (Zhao et al. 2022). Sea weeds are also considered to be a rich source of biohydrogen, one of the cleanest sources of energy today (Wyper et al. 2024). Hydrogen is being produced from biomass through thermochemical processes (Alvardo-Flores 2024). Biomass is an organic matter surrounding us that is derived from the forests and croplands. As against the fossil fuels that take millions of years to replenish, biomass resources regrow in a relatively short span of time. Crops, wood, animal waste, seaweed, etc. are the biomass that can be used as an energy source. Since the dawn of human civilization, there has been a practice of cooking food by burning of wood. Sun is the ultimate source of energy on this earth and the plants convert water and CO_2 into carbohydrate through

the process of photosynthesis. Carbohydrate-rich foods are good source of energy for all the animals including human beings. As the sources of biomass are unlimited, it is held as renewable source of energy supply. There is always scope to plant trees and grow crops. As such the wastes are always there to be used as biomass. Biomass is one of the oldest and cheapest forms of energy since the dawn of civilization. Biomass is held as a good source of energy and is harnessed in diverse ways (Perea-Morew et al. 2019; Ghosh et al. 2021; Negi et al. 2023; Heeraman et al. 2023). Biomass has a significant potential as green energy source and shares about 14% of the total energy demand on a global scale. India has a vast potential of harnessing biomass energy (Ghosh et al. 2021).

Next to China it is India that annually produces about 900 million metric tons of agricultural biomass. A large portion of this biomass is either burnt or decomposed in uncontrolled manner which reduces the amount of surplus biomass available. The need of the hour is to channel a significant portion of this phytomass for power generation. Biomass energy could be considered as a clean fuel because the plants that are its source capture almost as much CO_2 through photosynthesis as is released when the biomass is burned. This makes biomass a carbon neutral energy source. Biomass is the organic material that makes up plants and it can be converted into energy in a variety of ways. As on 31 March 2023, the estimated potential for renewable biomass energy in India was 28,447 MW (1.3%) against the total renewable energy power capacity of 2,109,654 MW, 13,818 MW (0.66%) from bagasse-based cogeneration in sugar mills of renewable energy was from bagasse-based cogeneration in sugar mills.

5.1.1 Background

Biomass cogeneration is a process that uses a single primary fuel to simultaneously produce electricity and heat. It is a well-advanced technology that has been around for over a century and is more efficient than using separate production process. India has a rich resource base for biomass-based energy from sources like stubble that creates big health problems in the Delhi NCR during the onset of winter (on account of burning of this agricultural residue by the small farmers in Haryana, Punjab, and western Uttar Pradesh). Vast amount of phytomass of grasses and aquatic weeds could be harnessed for the same. Economy of north-eastern states is much dependent on bamboos. Bamboo has been recently removed from the category of forest trees and as such is now open for unhindered use by the common people. Bamboos in major portions of India could also be used to produce cleaner fuels. Bamboo biomass is a renewable resource that can be converted into ethanol and bioenergy (Liang et al. 2023). It can be processed thermally or biochemically into energy products such as charcoal, pellets, and briquettes, as well as utilized as a firewood replacement. Bamboo biomass has various desirable fuel properties, including low ash content and alkali index, and can generate 1 kWh of energy from 1 kg of bamboo. This is comparable to the biomass requirements for wood products,

but superior to other biomass sources such as hemp, bagasse, and rice husk. Bamboo has great fuel characteristics and can be turned into solid, liquid, or gaseous biofuels. Humankind today is in the age of artificial intelligence (AI). A recent report has revealed that Google is now pumping out more greenhouse gases than before as it powers data centres needed to support AI. Google's climate changing emissions have increased 48% in the past 5 years, and this is at odds with a touted goal of becoming carbon neutral for the sake of the planet. Total greenhouse gas emissions in 2023 were 13% higher than they were in the previous year. The same was primarily driven by increased data centre energy consumption and its supply chain (ET Energyworld.com, accessed on 6 July 2024).

5.2 Recent Studies on Biomass Utilization

India today has to lose heavily on account of forest fires that are increasing every year on account of climate change caused by global warming. Pine needles, which grow abundantly in India's hilly areas, are a major global problem due to their extreme sensitivity to fire in dry and hot climes. Pinus needles provide a good source of bioenergy (Rana et al. 2023). A case study of Uttarakhand state in India revealed that the state produces a significant 1.67×10^9 kg of pine needles each year. The annual potential emission from forest fires was estimated to be 58.37×10^9 kg of CO2. Halba and Arora (2024) were able to design and evaluate the efficacy of a gasification-based supply chain for pine needles in Uttarakhand's Almora district. Emission calculations revealed that gasification plant capacity scenarios may potentially cut 44.63×10^6 to 46.16×10^6 kg of CO_2 equivalent emissions per year when compared to grid electricity, while satisfying almost 5.5% of Almora district's electricity consumption. Water-logged sites in India are major sites of infestation by the fast growing water hyacinth (*Eichhornia crassipes*) that is a good source of phytomass and could be harnessed for bioenergy on a big scale (Ighodalo et al. 2011; Moki et al. 2020; Nandi Yanto et al. 2023; Wembe et al. 2023). Emergent aquaphyte like *Ipomoea carnea,* growing lavishly in these sites also holds a similar potential (Saikia et al. 2015).

Mango leaves and wood are utilized for cooking and other household purposes. In rural areas, the leaves are collected by sweeping the orchard floor and stored for pretty long time. Mango holds a good potential for use as a biofuel (Das et al. 2013). A weed like *Cannabis sativa* of the family Cannabaceae grows abundantly alongside rural roads and wheat fields. Its leaves are source of intoxicants and are widely used as a mild narcotic known by the local name of *bhang*. The plant could be used as a potential biofuel (Tahir et al. 2020). *Calotropis procera* (Apocynaceae) also grows equally lavishly as a laticiferous plant and is held as a petro crop. Its bio crude is a rich source of triterpenoid hydrocarbon have successfully upgraded its bio crude to useful liquid fuels by developing conversion processes like fluid catalytic tracking. The fuel thus obtained was found to contain significant proportions of polyaromatic hydrocarbon (Korlipara et al. 2009; Rathore and Meena 2010;

Mahmoud et al. 2021). Pérez-Arévalo and Velázquez-Martí (2018) made a complete evaluation of the process of getting biomass from pruning residues of an ornamental moraceous plant called *Ficus benjamina* that generates a large amount of ligneous residues including the mixture of wood and leaves. Nitrogen content was found to be acceptable for its use as fuel. They obtained 19 MJ/kg mean calorific value that was due to the presence of volatile content and lignin. In India, there is an old practice of large scale plantation of moraceous species of *Ficus* on religious grounds. A large part of our country is bearing the onslaught of an invasive weed *Parthenium hysterophorus* that came to India with Mexican wheat during the pre-green revolution days (Bisaria 2010; Tahir et al. 2020). On account of its high fecundity, the weed has spread almost everywhere. The weed grows with minimum input of nutrients in various soil and climate regimes. Plants belonging to Moraceae, Euphorbiaceae, Apocynaceae, and Asclepiadaceae families are generally laticiferous and hence designated as petro plants. Latex in these plants contain liquid hydrocarbon that could be converted into high-grade transportation fuel. Latex bearing plants serve as renewable source of conventional energy. National Highway Authority of India plants majority of laticiferous plants belonging generally to the species of *Thevetia*, *Nerium*, *Alstonia*, etc. along its course. Animals refrain from feeding upon these plants which need to be exploited as biofuels on an organized scale. Investigations have been made on the biofuel potentials of halophytes growing in estuaries alongside the confluence points of rivers with oceans (Abideen et al. 2023).

Punjab, now bifurcated into two states of Punjab and Haryana, is an agriculturally improved zone of India. The two states grow wheat and paddy on a big scale. This zone produces a big amount of biomass. Biomass-based power generation plants use mostly paddy straw. Small farmers in this zone burn the straw as they do not have sufficient time and means to prepare their field for sowing of wheat at a short interval. This makes the situation unsustainable on account of huge number of farm fires that engulf even the national capital Delhi and the entire National Capital Region (Singh et al. 2021). Biofuels are now being used as aviation fuel as well (Baxter 2020). The first biofuel blended flight was put into operation by the US Air Force on 25 March 2010. Virgin Atlantic used algae as feedstock in its first commercial flight in the year 2008. India's first flight using biofuel flew from Dehradun to Delhi conducted during August 2018.

Search for efficient methods of utilization of different categories of biomass for human welfare has now become a global priority. Investigations on this aspect are being made on varying source materials including microorganisms (Zabermawi et al. 2022), algae (Voloshin et al. 2016; Ru et al. 2020), aquatic and other weeds (Alam et al. 2021; Koley et al. 2023), agricultural residues (Rautray et al. 2019), etc. Grasses find flood plains as suitable habitat for their growth. Quite a good number of poaceous and other grasses are rich in biomass that could be exploited as biofuel. An example could be cited of a versatile grass *Rhizopogon zizanioides.* Cellulose in this grass is abundantly found in lignocellulosic form. Subsamran et al. (2018) were able to obtain bioethanol from this grass through hydrolysis with action of crude cellulase enzyme. Regenerative food forests raised at a few places in India are

Fig. 5.1 Vetiver grass in Belwara village of Darbhanga district

proving much helpful in raising above ground and below ground biomasses. A 100-acre Vanya Organic Farm in the Khalghat area of Madhya Pradesh on the bank of river Narmada and a 40-acre Samar Shail Organic farm at Ramnagar, Purnea in Mithila area of Bihar have vetiver as a significant component of the food forests raised by the two activists. Besides growing the food products, the ingrained phytomass helps in restoration of the barren rocky and sandy patches in these regions (Bewtra 2023) (Fig. 5.1).

Like forest fires in hilly states, farm fires in Punjab, Haryana, and western UP are another vexed issue that requires devising proper scientific methods to contain them. Porichha et al. (2021) have analysed alternative methods for valorization of crop residues that are now being converted as bio bricks (Rautray et al. 2019). Freshwater pools in India get infested with macrophytes including the nymphaeids like *Nymphaea*, *Nelumbo*, *Nuphar*, and other aquatics belonging to the species of *Nymphoides*, *Ottelia*, *Trapa*, and a host of other angiosperms. With voluminous leaves containing fairly large amount of biomass, often their flowers/fruits are consumed and other parts are simply left apart. Their old leaves wither out as per natural cycle. There is scope for harnessing their phytomass for biofuel potentials. The case of a rooted-floating macrophyte like *Euryale ferox* also known as (makhana/gorgon nut/fox nut) could be cited as an example for its under exploitation as a

Fig. 5.2 Shows the *E. ferox* plants that have been outpaced by the menacingly overgrowing *M. vaginalis* plants. The latter established a foothold in makhana plots. Dearth of rain during the initial months of the crop helped *M. vaginalis* plant overgrow and thereby block the growth of *E. ferox* plants

biomass crop as well (Jha and Sinha 2024). But in order to harvest its seeds lying at the pond bottom through virtually sweeping the floor, the leaves are cut down and left to disintegrate and decompose in the pond itself. Nothing except seed is taken out of the system. It is imperative therefore that the voluminous and leathery textured leaves are exploited for biofuel purpose as well. The same could be done along with the associated weeds like *Monochoria vaginalis*, *Jussiaea* sp., *Marsilea* sp., etc. (Fig. 5.2).

5.2.1 Biomass-Based Hydrogen Production

World today is looking forward to the production of biomass-based clean energy of which hydrogen has emerged as the forerunner. Waste biomass is now being utilized as potential renewable source for hydrogen production. Nguyen et al. (2024) have scrutinized the recent advancements in the field of production of hydrogen through adoption of pyrolysis and gasification methods.

5.2.2 Varied Forms of Biofuels

Biofuels are fuels derived from biomass and generally include animal waste, algae, or plant matter. Biofuel is a renewable source of energy is derived from replenishable matter and is easy to extract. Ethanol is essentially ethyl alcohol or pure alcohol, and it is the most common alternative biofuel used in cars. Sugarcane and corn are the most common sources. Naturally, ethanol is clean releasing roughly 15% less greenhouse gas emissions. It is usually incorporated with other fuels to reduce carbon emission. Methanol is an alcohol used in motor vehicles. It is produced through the gasification of biomass at extremely high temperature with a catalyst. Biodiesel is a liquid biofuel that is derived from a combination of vegetables and fats and oils from both animals and plants. As compared with diesel as fossil fuel, it has a reduced amount of carbon and higher hydrogen and oxygen contents. It is nontoxic, biodegradable, and safe to handle and transport. Biobutanol is generally derived from algae and bacteria. It could be used directly in standard gasoline engines with no modification as it has a higher energy per unit. Biogas is a gaseous form of biofuel produced through anaerobic breakdown of biomass. It mainly consists of methane gas.

5.2.3 Generations of Biofuel

Food crops constitute the first-generation biofuel and have a negative net energy gain that is accomplished by emitting more CO_2 during production. This is as compared with what the feedstocks did capture during growth. Biofuels are also blamed for inflation in food prices. Biofuels made from non-food crops constitute the second generation and they are cost-competitive as well. Their net positive energy gains are higher. Algae represent the third-generation biofuels that produce more energy per hectare than the conventional plant materials. They generally grow in water bodies or land that is unsuitable for the production of food. Almost the same amount of carbon is absorbed and also emitted. The fourth-generation biofuels generate sustainable energy and provide a way to capture and store CO_2. This process differs from the second- and third-generation production in the sense that carbon dioxide is captured during all stages through oxy-combustion. Old oil and gas fields could be used for storing the CO_2. Such a type of CO_2 capture is an example of carbon negative category. The fifth generation includes biofuels derived from non-food sources through advanced technologies with algae, bacteria, and microorganism as the base material. Their processes are sustainable and environment friendly that provide high energy yields per unit of input. Cellulosic biofuels generally come under this category, processes of fermentation, tissue culture, genetic engineering, etc. are used for obtaining the fifth-generation biofuels (Mushtaq et al. 2023).

5.3 Policies on Biomass Utilization

The Ministry of New and Renewable Energy Sources created the first National Policy in 2009. This National Policy on Biofuels-2018 was developed on the foundation of previous policy successes and establishes a new agenda consistent with the redefined role of emerging advances in the renewable sector. The National Policy on Biofuels-2018 aims to expand biofuel use and minimize petroleum product imports by blending ethanol with petrol to 20% by 2025–26 and biodiesel to 5% by 2030. According to the 2022 Amendments to the National Policy on Biofuels, the aim for ethanol blending in gasoline has been moved from 20% by 2030 to 20% by 2025–26. The strategy has been expanded to incorporate more feedstocks for biofuel production. This comprises bamboo, bagasse, and corn stover. Domestic ethanol consumption has just overtaken domestic production for the ninth year in a row, with 2023 marking the milestone. In India, industrial ethanol is used for a variety of purposes although biofuels and additional neutral alcohol account for the majority of consumption. At present, India's industrial alcohol production capacity stands at 13.80 BL, with 8.75 BL from molasses and 5.05 BL from green livestock. Bioethanol provides a number of economic, social, and environmental benefits, including increased crop demand, increased employment, and lower emissions. According to the Indian government, measures associated with the India Ethanol Blending Programme reduced greenhouse gas emissions by 31.8 million metric tons between the ethanol supply years of 2014 and 2022. Despite problems such as feedstock availability and technology limits, policymakers, and producers are addressing the problem through better legislation, regulations, and technological advancements. The major states in ethanol production are Maharashtra, Uttar Pradesh, and Karnataka. Maharashtra generates 2.68 BL of ethanol annually. Uttar Pradesh and Karnataka produce 2.08 BL and 1.18 BL of ethanol annually, respectively. These states are at the forefront of industrial ethanol production due to their quantity of feedstock. These states are large sugarcane growers, with established distilleries. Corn production in India is predicted to increase by 10 million metric tons over the next 5 years, allowing for greater conversion to ethanol. The government is supporting the domestic manufacture of flexi-fuels and E-20 compliant automobiles in the Indian market to increase ethanol output and use.

According to the aims of the Global Biofuels Alliance (established recently at the 2023 G20 Summit), India plans to treble its biofuel use over the next 5 years. The Global Biofuels Alliance intends to incorporate biofuels into the world's energy mix by increasing the use of sustainable biofuels and allowing technological improvements. This is a tremendous potential for the Indian bioethanol industry to broaden its reach and influence towards a more sustainable future. High-gravity fermentation is an important approach to reduce energy use during ethanol manufacturing. New technologies and new techniques are likely to contribute to stronger bioethanol market dynamics. The second-generation bioethanol is expected to gain traction in the future years. The potential introduction of new generations of yeasts into the Indian market is expected to create numerous chances in this industry. The Govt. of

Table 5.1 Indian standards for biofuel

S. no.	IS number	Year	Specification
1	15464	2022	Blending component in motor gasoline anhydrous ethanol is used
2	15607	2022	Fatty acid methyl esters FAME—biodiesel B-100
3	16087	2016	Biogas–biomethane
4	16531	2022	Blend B8 to B20—biodiesel diesel fuel
5	16629	2017	ED95 automotive fuel—hydrous ethanol
6	16634	2017	Anhydrous ethanol and gasoline blend as E85 fuel
7	17021	2018	E20 fuel is a blend of anhydrous ethanol and gasoline used as fuel for spark-ignited engine-powered vehicles
8	17081	2019	Kerosene type, Jet A-1 containing synthesized hydrocarbons—aviation turbine fuel
9	17821	2022	Positive ignition engine-powered vehicles (ethanol used as fuel)

Adapted from Posted on: 25 Sep 2023, 4:48 PM by PIB Delhi

Bihar has also come up with its Bihar Biofuels Production Promotion Policy 2023 by amending its previous Ethanol Production Promotion Policy 2021. This policy aims to broadbase the coverage by including CBC (compressed biogas)/bio CNG manufacturing units apart from ethanol. The Bihar Biofuel Policy is a significant step forward for the state's future-cleaner, more self-sufficient, and economically prosperous. Bihar is enabling a more sustainable energy landscape while also empowering its people by creating jobs and economic possibilities through biofuel production and use. The Bureau of Indian Standards (BIS) is the primary national authority in charge of developing and executing the standards required for marking and quality certification. It enables the timely development, dissemination, promotion, and implementation of national and regional standards. It ensures technical regulations for goods, services, processes, and practices (Table 5.1).

5.3.1 Significant Highlights of the National Policy on Biofuels-2018

- Classification of basic (1G) bioethanol and biodiesel, and advanced (2G) biofuels such as ethanol, drop-in fuels, and algae-based biofuels (3G).
- To encourage the procurement of intermediate (B-Molasses), sugarcane juice, other sugar-containing materials, and damaged/surplus food grains to broaden the scope of raw materials for ethanol production.
- To focus on research and demonstration in the field of biofuel feedstock generation, enhanced conversion methods from specified feedstock.
- To encourage biodiesel production from non-edible oilseeds, spent cooking oil, short gestation crops, and the establishment of supply chain mechanisms.
- Setting up a national biomass repository by conducting biomass appraisals around the country.

Fig. 5.3 Shows an advertisement issued by the Govt. of Bihar regarding its Biofuel Policy 2023 (Rashtriya Sahara, Dated: 10 March 2024, Patna Edn.)

- To focus on Advanced Biofuels and offer a funding scheme of Rs. 5000 crore over 6 years for 2G ethanol biorefineries, with additional tax advantages and a higher purchasing price than 1G biofuels. Setting up of National Biofuel Coordination Committee (NBCC) under the Ministry of Petroleum and Natural Gas and Working Group on Biofuels.
- By 2030, the proposed objective is to blend 20% ethanol and 5% biodiesel in petrol (Fig. 5.3).

5.4 Efficient Cremation Systems

Brihanmumbai Municipal Corporation (BMC) is likely to implement an ecofriendly wood combustion system at several crematoria in Mumbai and its suburbs. The system was first piloted in 2020 and has proven successful. Fourteen crematoria have been recently identified to use biomass briquettes and pellets as alternative fuels. The combustion system is engineered to optimize energy efficiency and minimize smoke emissions. Advanced features like water scrubbers and cyclonic separators filler out particulates and toxic gases, ensuring cleaner air. The treated air is thus released through a 30 m high chimney. The wood burning system employs a specially designed combustion chamber that minimizes fuel usage. Traditionally, cremations require 350–400 kg of wood. However, this new system reduces wood consumption to 100–125 kg per cremation saving approx. 250 kg of wood each time. This reduction in wood usage also leads to lower carbon emission. Rural people in Bihar are now cremating corpses by either digging pits or in earthen

Figs. 5.4, 5.5, and 5.6 Show cremation under a closed system with dung cake as fuel

containers with cow dung cakes and maize cobwebs as fuel (Tewary 2009; Jha 2022) (Figs. 5.4, 5.5, and 5.6).

A project called GOBAR (DHAN) has been launched to keep villages clean while also enhancing the income of rural households. The initiative aims to focus on controlling and converting cattle dung and solid waste in farms into usable compost and bioCNG (Fig. 5.7).

5.4.1 Utilization of Human Waste

The concept of human waste utilization was enunciated by Padma Vibhushan Bindeshwar Pathak in Bihar who created a silent revolution through his Sulabh Shauchalaya Movement. Bioenergy generated from human excreta was once used for lighting Gandhi Maidan in the state capital "Sulabh" turned out to be a trendsetter in the field of human waste management (Mukherjee and Chakraborty 2016).

5.5 Conclusion

Biomass has since evolved as a promising source of renewable energy for which India has a vast potential. There is a need to extend all possible government and public support to meet the targets of Net Zero emission at the earliest through adopting the best possible ways. Biomass energy could play a significant role in obtaining the goals of energy transition and save the world from the on-slots of the menacing levels of climate change.

Fig. 5.7 Cremation in an earthen container placed over a boat in Kusheshwar Asthan area of Darbhanga district

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Clean Energy Production Technologies
Series Editors: Neha Srivastava · P. K. Mishra

Akhilesh Kumar Yadav *Editor*

Powering Future: Clean Energy Solutions for a Sustainable Planet

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The consumption of fossil fuels has been continuously increasing around the globe and simultaneously becoming the primary cause of global warming as well as environmental pollution. Due to limited life span of fossil fuels and limited alternate energy options, energy crises is important concern faced by the world. Amidst these complex environmental and economic scenarios, renewable energy alternates such as biodiesel, hydrogen, wind, solar and bioenergy sources, which can produce energy with zero carbon residue are emerging as excellent clean energy source. For maximizing the efficiency and productivity of clean fuels via green & renewable methods, it's crucial to understand the configuration, sustainability and techno-economic feasibility of these promising energy alternates. The book series presents a comprehensive coverage combining the domains of exploring clean sources of energy and ensuring its production in an economical as well as ecologically feasible fashion. Series involves renowned experts and academicians as volume-editors and authors, from all the regions of the world. Series brings forth latest research, approaches and perspectives on clean energy production from both developed and developing parts of world under one umbrella. It is curated and developed by authoritative institutions and experts to serves global readership on this theme.

Akhilesh Kumar Yadav
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Powering Future: Clean Energy Solutions for a Sustainable Planet

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Dedicated to Environmental Engineers and Scientists Around the World

Foreword

I must congratulate the editor for an excellent review of clean energy requirement and identification of the gaps in the present knowledge in the area of clean energy need for sustainable development. Dr. Akhilesh Kumar Yadav's hard work to bring this volume is highly appreciated.

The contribution of eminent academicians is distinctive, appropriate, and judicious for the sustainable growth on the planet earth.

Our relationship with the world is significantly impacted by energy. We must acknowledge that the reliance on fossil fuels is unsustainable. Our future is at risk due to environmental degradation, climate change, and resource depletion. As you embark on this journey toward a brighter future, this book, *Powering the Future: Clean Energy Solutions for a Sustainable Planet* will engage you in a captivating examination of the technologies that are on the brink of revolutionizing our energy landscape. This book explores many renewable energy sources, including solar panels and geothermal electricity. The document contains details regarding nuclear energy and the remarkable wind turbines that harness wind power. The journey continues throughout each subsequent generation. Sustainability requires the utilization of two separate approaches and a more thorough examination. This book explains the fundamental concepts of energy efficiency and conservation, allowing us to decrease our use and maximize our resources. The book's writing style is both accessible and fascinating, making it a suitable choice for anyone with an interest in energy and environmental subjects. This comprehensive resource is intended for inquisitive individuals seeking to acquire knowledge, influential decision-makers who define our future, and ambitious business executives who are catalysts for change. Adhere to the guidelines outlined in this paragraph. Let it inspire you to promote and back the adoption of sustainable and eco-friendly energy options. The advent of renewable energy heralds a promising future that begins right now.

Director, Indian Institute of Technology Patna
Patna, India

Triloki Nath Singh

Preface

The motivation behind this volume, titled *Powering the Future: Clean Energy Solutions for a Sustainable Planet,* is to present innovative techniques for securing a sustainable future. This book serves as your guide to understanding the cutting-edge technologies driving you towards a cleaner, more sustainable world. It covers a wide range of topics, from harnessing the sun's energy through solar panels to tapping the earth's geothermal heat, from wind power captured by majestic turbines to the potential of nuclear energy. However, clean energy is not only about generation; it also involves using less energy. This contributed book highlights the critical role of energy efficiency and conservation in achieving sustainability. Written in a clear and engaging style, it empowers readers with a broad interest in energy and environment. The content is rich with informative text that is easy to follow, complemented by diagrams and photographs. Whether you're a curious citizen, policy-maker shaping the future, and business leader driving change, this contributed book is an essential resource for you. The book is organized into five sections. **Part I** provides an overview of wind energy and ecological sustainability with four chapters. **Part II**, which consists of four chapters, focuses on biomass and biogas, while **Part III** covers solar energy in three chapters. **Part IV** is dedicated to solar technology with three chapters, and the final section, **Part V**, consists of four chapters addressing clean energy solutions.

I would first like to thank the Almighty for His blessings throughout the completion of this project, enabling us to successfully explore this challenging research domain with a technical perspective. The authors are sincerely grateful to Springer for the opportunity to publish this work on such a contemporary topic of modeling and simulations. Special thanks go to all the contributors who made this volume a valuable source of knowledge, reporting the latest findings in their respective fields. Out of 76 abstracts submitted, 47 were selected for full chapter contributions, and 18 chapters were ultimately included, based on scope and quality of the submissions. The authors have shown tremendous effort throughout the process, from writing and revising based on comments to addressing Springer's evaluation reports and final proofreading. The review process adhered to a double-blind method, where both authors' and reviewers' identities were kept confidential to ensure unbiased

decision-making. I also like to thank the Springer publication team for their timely responses and guidance. Lastly, I acknowledge Jaydeep Kumar (BCAS, New Delhi, India) and Advocate Dinesh Chandra Gupta (High Court, Allahabad, India) for their unwavering help and support during the execution of this project.

The editor welcomes any feedback, comments, or suggestions to improve future editions. Proposals for new chapters for subsequent editions are also encouraged and can be sent directly to the volume editor.

Taichung, Taiwan Akhilesh Kumar Yadav

Contents

About the Editor

Akhilesh Kumar Yadav, Ph.D., MIE, earned a Bachelor of Technology (B.Tech.) in Electronics and Communication Engineering from Chaudhary Charan Singh University in Meerut, India. He then obtained a Master of Technology (M.Tech.) in Environmental Engineering from Madan Mohan Malaviya Engineering College in Gorakhpur, India (affiliated with Dr. A.P.J. Abdul Kalam Technical University, Lucknow). His doctoral degree, with a research focus on air pollution, was awarded by the Indian Institute of Technology (BHU), Varanasi, India.

Dr. Yadav has served at various institutions, including Indian Institute of Technology (Banaras Hindu University), Varanasi, India; Indian Institute of Technology Bombay, Mumbai, India; Bhabha Atomic Research Centre, Mumbai, India (as a research collaborator); and Chaoyang University of Technology in Taichung, Taiwan. He has authored/co-authored several research and review articles, book chapters, and edited/authored books, and holds a patent.

Dr. Yadav received the Young Engineer Award from the Institution of Engineers (India) and the Young Scientist Award from VDGOOD Technology Factory, Kolkata. His research interests include air, water, and soil pollution; climate change; vulnerability; human health risk assessments; and GIS applications in environmental pollution and management. He is an active member of several reputed international professional bodies, including the IEI (Kolkata), ECI (New Delhi), AEACI (Mumbai), MSI (New Delhi), and IASTA (Mumbai).

Part I
Wind Energy and Ecological Sustainability