



Review article

Waste to energy conversion for a sustainable future

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ABSTRACT

Air pollution, climate change, and plastic waste are three contemporary global concerns. Air pollutants affect the lungs, green gases trap heat radiation, and plastic waste contaminates the marine food chain. Two-thirds of climate change and air pollution drivers are emitted in the process of burning fossil fuels. Pollutants settle in months, green gases take centuries, and plastics take thousands of years. The most polluted regions on the planet are also the ones that are greatly affected by climate change. Air pollutants grow in most climate-change affected areas, contributing to the greenhouse effect. Smog affects local and regional transboundary countries. The biggest greenhouse gas (GHG) emitters may not be the worst-hit victims because wind and water flow distribute green gases and plastic waste worldwide. The major polluters are often rich and developed countries, and the worst affected countries are the underdeveloped poor communities. Technologically advanced countries may help the developing countries in research into removing particulate matter, green gases, and plastic waste. Intergovernmental Panel on Climate Change (IPCC) and Paris Accord have emphasized on immeasurable efforts to encourage the conversion of pollution, green gases, and plastic waste into energy. Conversion of CO₂ into petrol, GHG gases into chemicals, biowaste into biofuels, plastic waste into building bricks, and concrete waste into construction materials fosters a circular economy. This work reviews existing waste to power, energy, and value-added product conversion technologies.

1. Introduction

Pollutants, green gases, and plastics constitute three vortices of the waste triangle. Domestic waste consists of hydrocarbons that can be converted into electricity using thermoelectric and anaerobic digestion plants (Abas et al., 2018b; Fan et al., 2020). This combustion process produces pollutants and green gases. Damaged roads and building infrastructures may be converted into useable heat energy storage materials (Ho et al., 2020). Waste conversion to watts, energy, and value-added products (chemicals) is the way forward for long-term sustainability. A number of reports have been cited that show considerable progress in the transformation of pollutants into hydrogen (Verbruggen et al., 2017), green gases into green energy (Stroud et al., 2018), biomass into biofuels (Zhang and Zhang, 2019), and plastics into building bricks (Lundquist et al., 2020). Waste from one industry (e.g., tires) may be used as a raw material for the second or third industry (e.g., pyrolysis plants). Circular economies should be advocated for a sustainable development program while minimizing linear economies (Geissdoerfer et al., 2017). A linear economy follows take, make, use, dispose, and pollute, whereas

a sustainable circular economy promotes take, make, use, reuse, and recycle steps, as shown in Figure 1.

The combustion of fossils account for more than two-thirds of global air pollution and climate change. Most polluted countries also happen to be the ones that are severely affected by global warming (AQI, 2019). Ocean waves and tides distribute local and global plastic waste into coastal regions and ocean gyres. The GHG emissions released into the atmosphere form a cohesive thick shield around the earth, accelerating climate change. Green gases trap the heat released by the earth to balance the global radiation budget. Air pollution by cars, factories, buildings, and power plants directly affects humans, animals, and plants. Fossil fuel (oil, gas, coal, shales, and biomasses) combustion is the primary cause of climate change. Hydrocarbons drive climate change and air pollution circuits. Air pollutants, including PM_{2.5}, PM₁₀, NO₂, SO₂, CO, and O₃, and greenhouse gases (GHG), consist of CO₂, CH₄, N₂O, SO₂, CO, O₃, and chlorofluorocarbons (CFCs). The common gases responsible for air pollution and global warming are shown in Figure 2.

NO₂ and nitrous oxide gases are primarily not green but mediate ozone formation, a green gas in the troposphere. Water vapors are natural

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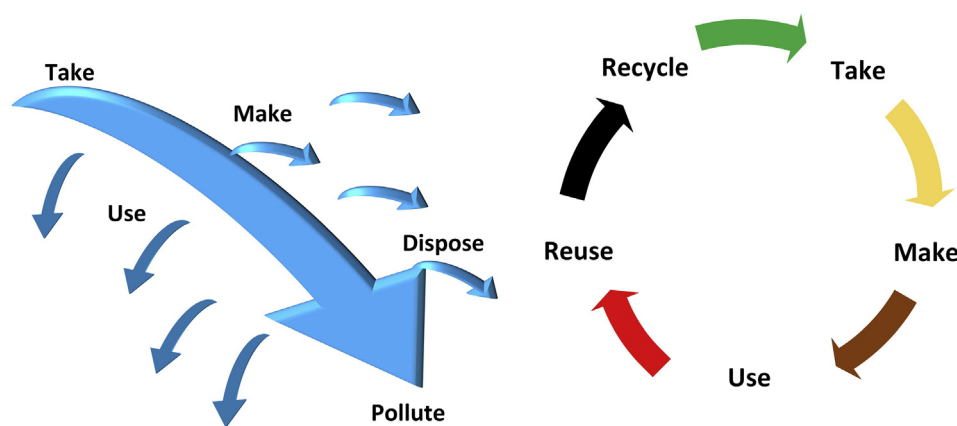


Figure 1. Vision of linear and circular economies.

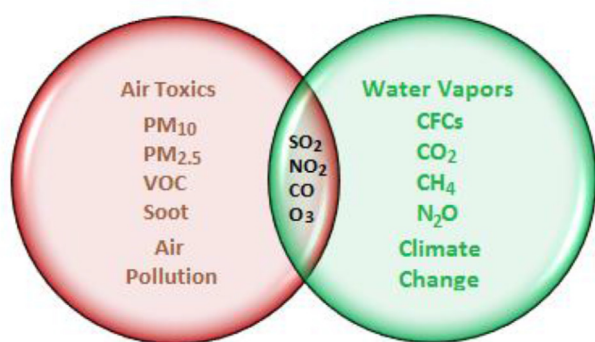


Figure 2. Common gases causing air pollution and climate change.

GHG. Green gases play an essential role in maintaining warmth on the planet. The natural temperature would be -18°C , instead of 15°C , without green gases, particularly water vapors. Global warming is caused by excess GHG emissions. By contrast, global cooling is due to a lack of GHG emissions. Heatwaves and cold snaps experienced revealed that it is difficult to compete in extreme weather. Combustion of fossil fuels spawns air pollutants and green gases. Most GHGs come from the combustion of fossil fuels (77%), agriculture (10%), industry (8%), and waste (3%). Three percent means 1.2 Gt annually ($3 \times 40/100$). European waste-related GHG emissions used to be 5.2 million tons in 2008; however, they will be less than 4.4 million tons by 2021. Majority of the GHG emissions originate from solid waste, with some from wastewater and the smallest amount from burning of waste. US and China account for half and one-third of the total GHG emissions from food waste, respectively. The carbon footprint of cereals, vegetables, and meat is more than that of milk, oils, and fruit crops (FAO, 2013).

China and India are major polluters and emitters in Southeast Asia. Karachi and Mumbai are the most polluted coastal cities, which have recurrent heatwaves in summers and cold snaps in winters. Lahore and New Delhi are the most polluted cities, which have frequent dust storms and heatwaves. Indian Ocean dipole effect, which is caused by ocean surface temperature difference (e.g., El Niño), causes flash floods in the Eastern regions of Africa with droughts in Southern Australia (BBC, 2019). Australia is also affected by ozone depletion. Chinese CO_2 emissions are more than the combined emissions of America (15%), India (7%), and Russia (5%). In US, the CO_2 emissions are more than the combined emissions of India (7%), Russia (5%), and Germany (2.5%). China emits more GHG than EU and U.S. combined; meanwhile, India releases more GHG compared with the seven SAARC countries combined (Rapier, 2018). Annual air pollution-related deaths recorded in India and China were 3.2 and 1.8 million in 2017. US is at number 7 in terms of 0.2

million pollution-related deaths. According to Global Alliance on Health and Pollution (GAHP), more than 8.3 million people died in 1 year due to air pollution-related diseases (AFP, 2019). Natural winds sweep pollutants and GHG emissions into Pakistan from upwind CO_2 spewing countries. Pacific Ocean waters shift the pollution and GHG to North America, which is the ultimate sink of CO_2 . Since 1980, every subsequent decade is warmer than the earlier decade. Year 2019 was the second or third warmest year after 2016 due to El Niño conditions. World Meteorological Organization in COP25 alarmed the thermal runaway through cascading impacts and collapse of ecosystems. Emissions of CO_2 , CH_4 , and NO_2 have reached 147%, 259%, and 123% of pre-industrial level emissions. The World Health Organization (WHO) informed the world in a Climate Summit (Madrid) that air pollution kills more than 7 million people in 1 year, with 4.1 million projected in 2016. Global average temperature and sea level steadily increased in 2019 (Kalair et al., 2019).

According to NOAA measurements, the global CO_2 , N_2O , CH_4 , and CF_{12} concentrations were 810, 333, 1875, and 500 ppt in 2019. CO_2 alone has a concentration of 410 ± 1 ppm, while all green gases together have a concentration of 490 ppm. The CO_2 concentration in the air was 409.50 on 22 December 2018, which increased to 416.56 on 17 June 2021. There is a continually rising trend in CO_2 , N_2O , CH_4 , HFC-134a, and HCFC-22. Although the global ban on CFCs has led to a decreasing trend of CFC-12 and CFC-11 gases, their concentrations in air are still more than HCFC-22 and HFC-134a (NOAA, 2019). COP25 has ended without any consensus on GHG reductions and carbon market. Concentrations of GHG emissions are shown in Figure 3.

In the last 160 years, oxygen levels in ocean waters have depleted by 2%. It will likely increase to 3%–4% by 2100 (IUCN, 2021). Oxygen depletion by global warming in the presence of ocean acidification is likely to affect marine species in the top 1 km layer of water. Higher temperatures increase oxygen demand by ocean biological systems that pose risks to tuna, marlin, and shark fishes (Harvay, 2019). Bird and animal species are facing extinction on land. America may lose 389 out of the 604 (two-third) marine species due to rising ocean temperatures, heavy rains, and accelerated urbanization (Holden, 2019). According to Bateman, environmental destruction can easily be viewed through observation of birdlife because they are easily visible and quick to respond. Animals can migrate to more favorable weather conditions; nonetheless, two dozen animals face a serious risk of extinction today (Wenz, 2019). Migrating wild animals pose a threat to people in the Himalayan valley and Arctic circle (Hanson, 2019).

It is ideally a survival war between animals and humans. Simple changes in our lifestyles can greatly help, such as recycling as much as possible (47%), replacing petrol cars with hybrid (38%), buying green energy (34%), living without cars (28%), eating a plant-based diet (20%), drying clothes in sunlight (14%), replacing bulbs with LED lamps (14%), having few children (11%), and avoiding long flights (10%). Reuse, recycle, and repair culture guarantees sustainable living. The air consists

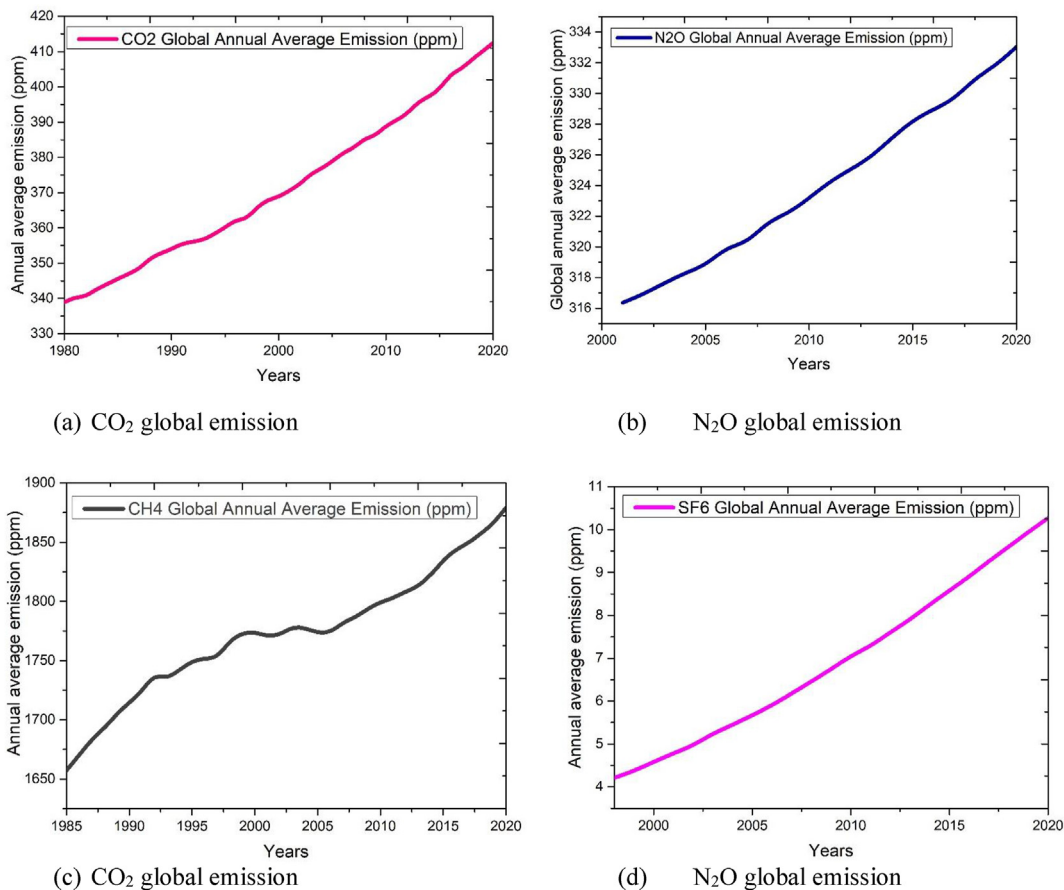


Figure 3. Atmospheric concentrations of major GHG emissions (Courtesy of NOAA, 2019).

of 79% nitrogen and 21% oxygen, whereas diesel encompasses 97% hydrocarbons and 3% sulfur; lube comprised 97% hydrocarbons, 2.5% calcium, and 0.5% sulfur, which produce NO_x and SO_x, CO, H₂O, and HC gases and aerosols when burned, as shown in Figures 4 and 5 (Data source (EEA, 2008; MAN; and B&W, 2004)).

Farm, fields, forest, and factory fires spew PM₁₀ particles, and oil, gas, coal, and shale combustions release PM 2.5 particles. Fire kilns, waste, and stubble burning practices continuously pollute the atmosphere. The

government ban on stubble burning in farms, forest management, district administration actions against waste burning in cities, and strict regulations on vehicle manufacturers on engine design can reduce emissions. The composition of spark-ignited internal combustion engines consists of 71% N₂, 18% CO₂, 9.2% H₂O, and 0.7% by volume O₂ and noble gases. Pollutants in gasoline exhaust include 0.85% CO, 0.08% NO_x, 0.05% unburnt HC, 0.005% particulate matter (PM), 0.115% SO_x, and others (Bera and Hegde, 2012). Diesel engine intake consists of air, fuel, and lube.

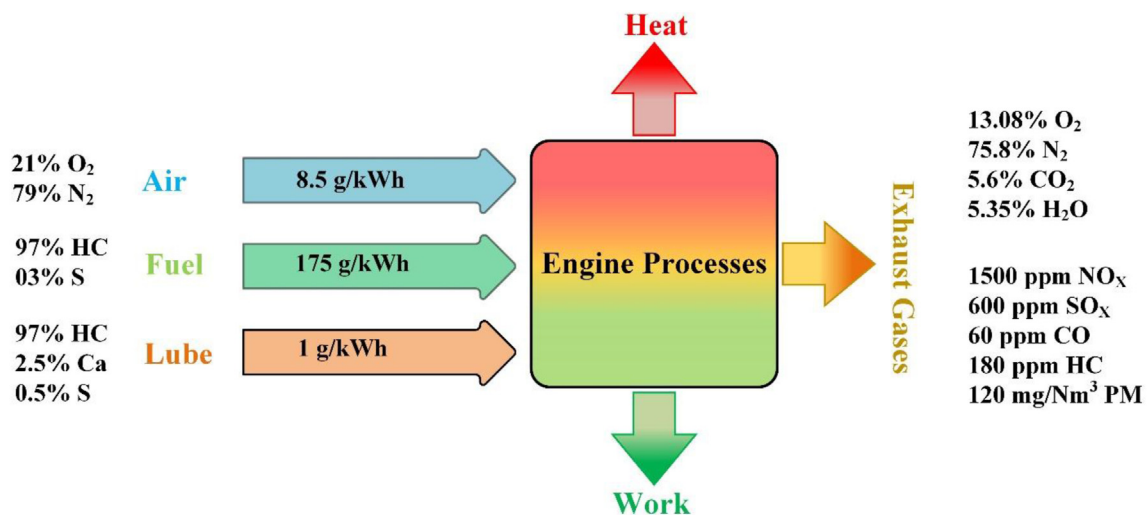


Figure 4. Typical emission from MAN B&W MC low-speed diesel engine.

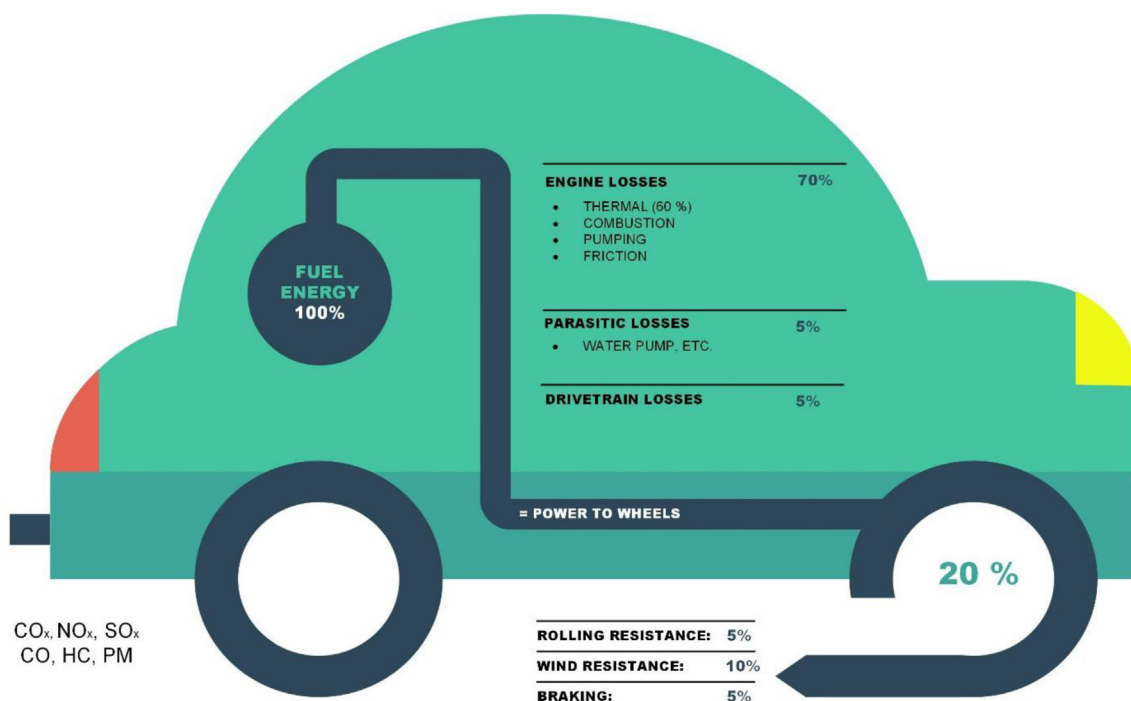


Figure 5. Motor efficiency, losses, and exhaust.

Diesel vehicles emit more SOX than gasoline and gas engines. Human activities being stationary (34%) and biomass (22%) burning contribute most NOX in the air. Natural and manufactured sources, each contributing 15% NOX, include soils, lightning, and mobile. Internal combustion engines are the most significant contributor of NOX, SOX, and COX pollutants. Petrol cars emit more CO and HC compared with diesel cars, which expel more PM and SOX. Electrolytic converters reduce CO to CO₂, and the overall result is the reduction of NOX, SOX, CO, and HC at the expense of more CO₂ emissions. Diesel engines are more efficient than petrol engines. Petrol engines without catalytic converters emit more carbon monoxide, hydrocarbons, and nitrogen oxides than diesel engines (Dey and Mehta, 2020). Comparison of emissions of petrol and diesel vehicles for 1 km journey are shown in Table 1.

The total SOx emissions account for up to 178.379 tones/year, NOx 141,892 tones/year, and CO 11235.135 tones/year. SOx emissions are majorly emitted from diesel cars and motorcycles. CO emissions outweigh NOx and SOx in terms of emission volume (Boedisantoso et al., 2019). Emissions of LPG and CNG vehicles are lesser than petrol and significantly lower than diesel vehicles. PM₁₀ exhaust emissions have been reduced from 30 mg/km to 10 mg/km from 2005 to 2015 (Hoofman et al., 2016). Several emission limitations exist; however, the primary focus is on reducing NOx and SOx emissions because these pollutants pose a threat to human health, plants, and the environment. Despite all measures by the vehicle manufacturers, the pollutants will continue to increase if we do not transition to renewable energy-powered electric vehicles, hydrogen fuels, or pollution to power/products conversion processes.

Table 1. Vehicle emissions mg per km journey.

Vehicles	CO	CO ₂	HC	NO _x	SO _x	PM
Petrol engine without a catalyst*	100	100	100	100	100	100
Petrol engine with a catalyst	42	100	19	23	NA	30
Diesel engine without a catalyst	2	85	3	31	100	100

* Petrol cars (non-catalytic) are given a relative value of 100 for comparison (Motor Vehicle Emission Controls).

2. PM

Suspended PMs (SPMs) persist in the atmosphere in solid and liquid phase matters. The sources of these PMs are natural and anthropogenic. SPM may include thoracic, respirable particles, inhalable coarse particles (PM₁₀), fine particles (PM_{2.5}), ultrafine particles, and soot. PM₁₀ and PM_{2.5} particles are harmful forms of air pollution due to their inherent ability to penetrate well deep into lungs and bloodstreams. PM particles can cause premature death by heart and respiratory diseases. PM pollution emanates from construction activities, agriculture waste, fossil fuel combustions in automobiles, forest fires, stubble burning, industrial processes, fire kilns, chemical, and power plants. The sources of PM pollution are atmospheric PM, marine, and space debris. The natural sources of PM pollution are dust storms, volcanic eruptions, wildfires, and sea salt sprays (Seinfeld and Pandis, 2016).

Human activities producing PM pollution include fossil fuel combustion in vehicles, fire kilns, industries, power plants, stubble burning in farms, fireworks, roadside dust, domestic waste combustion, and industrial processes. Coal-burning for residential heating and power generation is a significant source of PM pollution. Seaspray on oceans is one of the most common forms of PM pollution in the atmosphere. Aerosols (e.g., sea salt) and marine debris (e.g., litter) refer to suspended SPM in water bodies. Pollutants in the air fall on water or land as acid rain. A wide range of marine aerosols is produced during the bubble bursting of breaking waves in oceans. Annual emission of sea salt aerosols amounts to 2000–10,000 Tg. Marine debris modifies the natural radiation budget by scattering light, condensation of clouds, and nuclei ices. Marine debris interacts with anthropogenic pollution to change biogeochemical cycles. Space debris refers to PM pollution in the vacuum of outer space. Debris of discarded technology in space is mostly from defective satellites: inactive debris, fragmented debris, and microparticles, exploded satellites persist in the geocentric orbit around the earth. Space debris include particles, gases, and space glow. The pollutant types and sizes from nm to mm range are shown in Figure 6 (data source Topper.com, 2021).

The global PM₁₀ concentrations of 70 µg/m³ and PM_{2.5} concentrations of 35 µg/m³ caused 15% mortality rates worldwide. In 2013, a European study found that PM₁₀ and PM_{2.5} pollutants increase 22% and

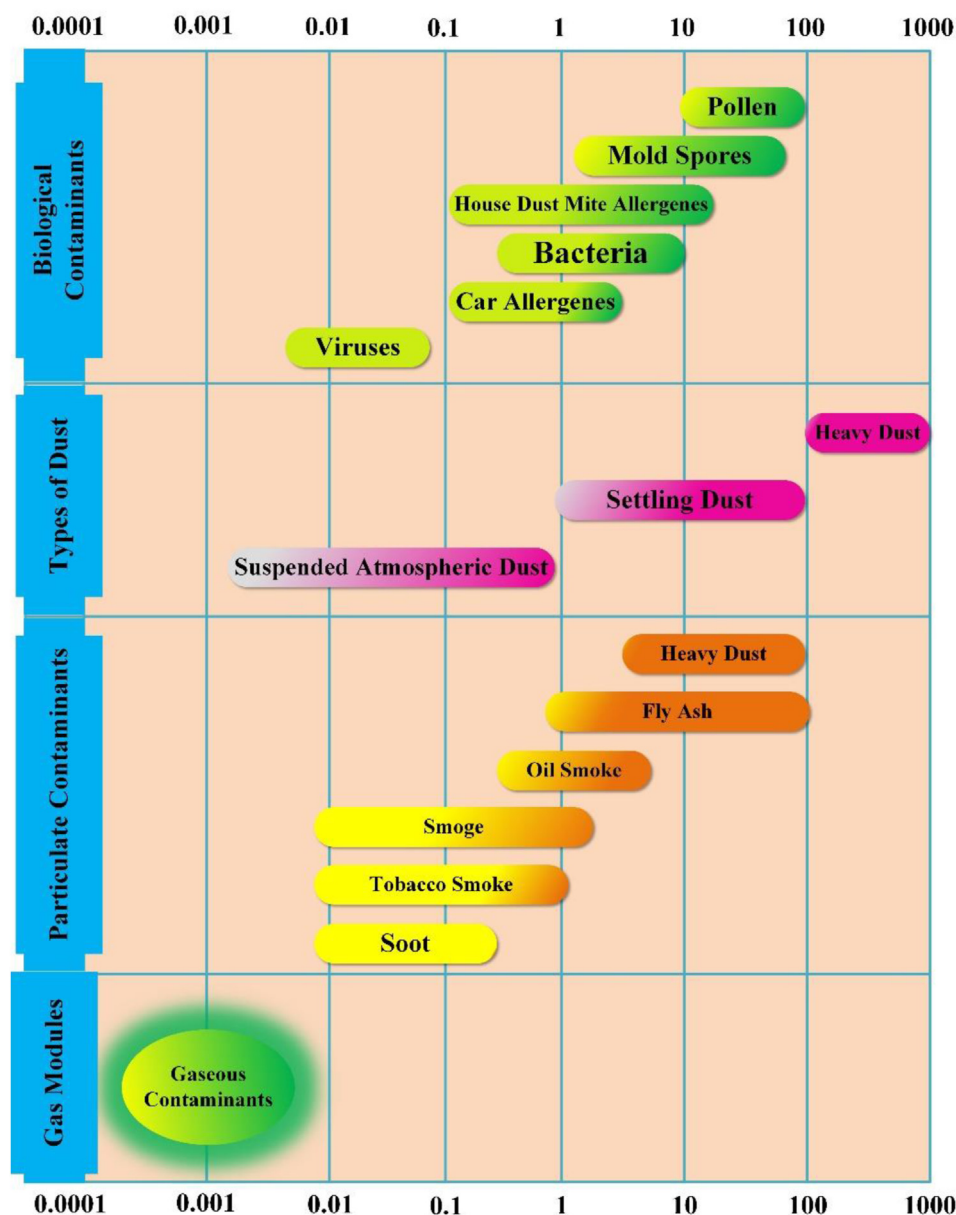


Figure 6. Types and size ranges (in μm) of air borne particles.

36% lung cancer rates for every increase of $10 \mu\text{g}/\text{m}^3$ (Raaschou-Nielsen et al., 2013). In 2016, 4.2 million premature deaths occurred due to airborne PM_{10} and $\text{PM}_{2.5}$ particles. Majority of these deaths (91%) fall in lower and middle socio-economic status communities. Among these deaths, a large portion (58%) were attributed to strokes and ischemic heart diseases, 8% to chronic obstructive pulmonary disease, and 6% to lung cancer (WHO, 2018). The US Environmental Protection Agency (EPA) revised the threshold concentrations of $\text{PM}_{2.5}$ and PM_{10} particles. The US EPA National Ambient Air Quality Standard decreased $\text{PM}_{2.5}$ daily exposure limit from $15 \text{ mg}/\text{m}^3$ to $12 \text{ mg}/\text{m}^3$ in 2012. Accordingly, the annual average $\text{PM}_{2.5}$ limit decreased from $12 \text{ mg}/\text{m}^3$ to $8.02 \text{ mg}/\text{m}^3$.

Stubble-burning practices in the Punjab region of India and Pakistan cause severe smog. This process starts around 15 October and remains until 15 January every year. In addition to stubble burning, the motor-bike, rickshaw, diesel trucks, and old gasoline cars make cities gas chambers. Health authorities often advise closing schools during peak smoggy days. Nevertheless, smog season is starting, and air quality indices are overshooting in both across border cities. Pakistan has officially ordered to close fire kiln and smoke-producing industries. There

are few stubble-burning complaints in Pakistan. However, Indian farmers do not listen to incumbents. Air quality indices for Lahore and New Delhi on 12 November 2019 are shown in Figures 7 and 8, respectively.

The composition of primary air-borne aerosols is dependent on the source. The wind-blown dust is composed of mineral oxides and materials in the local earth's crust. Sea salt is the second most abundant source in the global aerosol accumulation. Seaspray encompass NaCl , Mg , SO_4 , Ca , and K . Wet cooling towers in industries spread a wide range of pollutants. Secondary particles are formed by oxidation of primary gases, with the anthropogenic or biogenic origin, such as SO_x to sulfuric acid (liquid), nitrogen oxides into HNO_3 (gas), and ammonium salts into radiation scattering ammonium sulfate or nitrate (dry or aqueous). Organic matter may be either primary or secondary light-absorbing aerosols. Elemental carbon (black carbon) is strongly light-absorbing in nature. Black carbon particles in glaciers expedite their fast-melting by light absorption process. Tar-balls emitted by combustion engines pose a danger to health (Barringer, 2012). The composition of aerosols determines the refractive index that absorbs or scatters light. Smog is a combination of smoke and fog that consists of SO_2 , NO_2 , CO , and PM

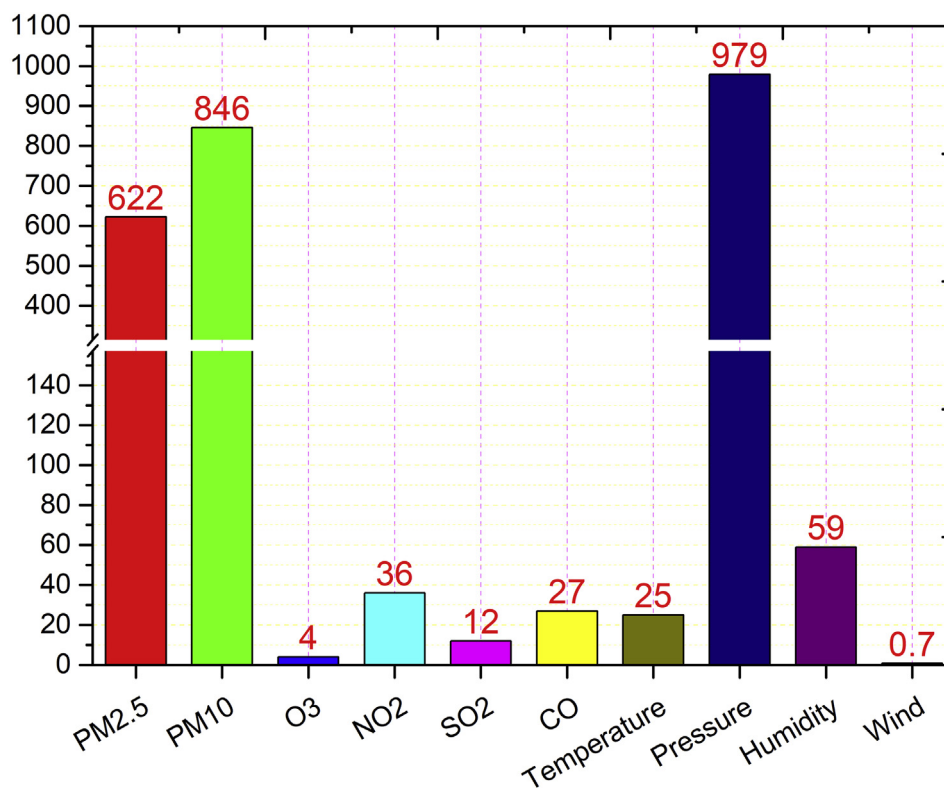


Figure 8. Air quality index of New Delhi on 12 November 2019 (WAQI, 2020).

CO₂ is combined with waste materials, such as left filtrate ash in burning coal or from coke, to create nanoparticles that can be added to plastic, concrete, and coatings of materials to improve performance and efficiency, according to the company's requirements (Popper, 2014). The use of these nanoparticles prevents radiation from entering the atmosphere and reduces the demand for carbon-rich resources, such as concrete, plastics, and coating materials.

Bioplastic formation is a process for catching CO₂ or methane from a power plant chimney stream or farm and mixing it with a microorganism that removes the carbon from CO₂ or natural gas. Subsequently, the collected pure carbon is mixed with oxygen and hydrogen to yield a PHA-based bio-polymer substance, which is then sterilized and pelletized before being melted into various forms (Gomez et al., 2019). In 2016, New-light and IKEA entered into a collaborative technology and supply license agreement that allows the manufacture of thermoplastic furniture using the emerging New-light technology. IKEA's goal is to use 100% recycled materials. CO₂ can be converted into fuel and methanol through an artificial method, such as photosynthesis. Conservative methanol, a liquid petrochemical, can be utilized in manufacturing pharmaceuticals, resins, perfumes, and an array of many more products. Industries compete to develop the best procedure for converting waste CO₂ into methanol fuels, often known as hydrogen (Lee and Lee, 2016).



C4X reacts with CO₂ to extract ethylene glycol, methanol, and bio-composite foam plastic. Many natural fibers, such as sawdust, rice keels, palm fiber, and flaxes, can be used to create biological composites. These materials are increasingly being used to substitute petrochemicals in green products. Engines convert carbon-based fuels into CO₂. The diesel engine is a relatively better machine in producing lesser CO₂ emissions compared with gasoline engines (Gotmalm, 1992). Carbon

materials are increasingly being used in the synthesis of photocatalysts (Kandy, 2020).

4. Nitrogen oxides (NO_x)

Vehicle combustion exhaust, coal burning, oil, diesel, and natural gas use in thermal power plants generate NO_x pollution. In addition, gas stoves, kerosene oil stoves, cigarettes, and wood fires emit NO_x. Nitrous oxide (laughing gas) is a pollutant and greenhouse gas that contributes to global warming. Humans are exposed to nitrogen oxides by breathing and skin contact. Nitric oxides, which are prevalent in contaminated air, can be utilized in a variety of industries. We can install extraction towers to collect NO_x. Nitrogen oxides, which are present in the air, can be used to produce HNO₃. Gas scrubbing is the most common and least expensive method of converting nitrogen oxide into HNO₃. HNO₃ is used in a variety of ways in everyday life, including medical, industrial, and commercial settings. NO and NO₂ are anthropogenic acid gases that form acid precipitation and photochemical smog in the atmosphere. Smog affects humans, animals, plants, and materials (EPA, 1999). Experts propose combined plasma scrubbing (CPS) to remove NO_x and SO₂. The market is flooded with a variety of methods to reduce NO_x emissions. H₂O₂ and HNO₃ may scrub NO and NO₂. It requires 0.37 lb of H₂O₂ for 1 lb of NO₂ and 1.7 lb of H₂O₂ for 1 lb of NO at moderate 30 °C–80 °C temperature.



Based on the equations above, we may receive distilled water and HNO₃ that can be utilized in industries for other processes after gas scrubbing NO₂. The HNO₃ obtained after converting NO₂ to HNO₃ is utilized in various applications. The reaction of HNO₃ with metals has been studied for a long time because it is the best solution for removing

oxides from metallic surfaces and prevent corrosion. It is also used in the making plastic and manufacturing dyes. Ammonium nitrate is a white crystalline solid used to improve soil fertility because it is highly soluble in water. It is produced when ammonia reacts with HNO_3 (Korshunov et al., 2003).



Thus, the HNO_3 derived from polluted air has a wide range of uses.

Aqua regia is a compound used to dissolve metals, such as Pt and Au. This solution is prepared by reaction of hydrochloric acid with HNO_3 . We can use this solution for dissolving metals (Flagan and Seinfeld, 2012). HNO_3 produced from the oxides of nitrogen is widely used in daily and industrial applications. HNO_3 is used in laboratories to carry out different experiments in everyday life. HNO_3 is most commonly used to make either white precipitate or silver chloride in silver nitrate solution. It also has a wide range of medical applications; a dilute solution of HNO_3 is used to treat dyspepsia. The reactions that contribute to the production of NO and NO_2 in fire flame are as follows:



NO_x emissions from Japanese two and four-stroke engines account for 50% and 10% of global NO_x emissions. Engines are being improved to reduce emissions. Asian markets are flooded with Japanese vehicles. Direct water injection technology may help us attain a 50%–60% reduction of NO_x in the exhaust. The standard catalyst reduction technology attains 85%–95% reduction of the NO_x in vehicle exhaust (MEPC 44, 2000). The primary NO_x reduction methods include altered or retarded fuel injection, nozzle modification, water addition, intake air humidification, water emulsification, exhaust gas recirculation, and changes in engine compression ratios. The secondary methods may include treating NO_x downstream and selective catalytic reduction, which can result in 90%–95% decline. Ammonia and exhaust reactions are as follows:



5. SO_x

SO_2 is a significant pollutant that has a serious effect on human health (US EPA, 2019). The presence of SO_2 in the atmosphere is hazardous to living things, including plants, communities, and animals (Hogan, 2011). Acid rain has been observed on Venus due to this compound. EPA has introduced a technology to reduce SO_2 in power plants. However, CaO may react with SO_2 to produce CaSO_3 .



Oxidation of CaSO_3 produces CaSO_4 . Flue gas is a significant source of gypsums marketed as produced by desulphurization of flue gases. The sulfur may effectively be minimized in coal-burning by using limestone in the combustion as the bedding material (Lindeburg, 2013). In the contact process, SO_2 is oxidized to react with oxygen and water to form sulfuric acid.



SO_2 in the air has a significant impact on acid rain. SO_2 is often used to preserve dried apricots and figs to protect against bacteria and other rotting viruses (FSA, 2020). This preservation method maintains the color and appearance of fruits fresh.

SO_2 can decolorize a substance when added to the water. It is used as a bleach for paper and clothes, although its bleaching effect does not last quite long. Oxygen can be used to restore colors. SO_2 reduces free and compounded chlorine atoms into chlorides (Hoffman, 1990). SO_2 is well soluble in water and shows spectra of the hydrogen sulfite ions when reacted with water.



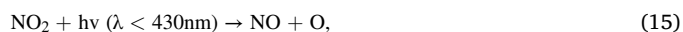
SO_2 quickly condenses and has a high heat of evaporation, making it an excellent refrigerant. Before the 1930s, SO_2 used to be a popular refrigerant for home refrigerators when CFCs were yet available.

The amount of SO_x produced in combustion is directly proportional to the sulfur concentration in fuel. Sulfur in fuel is released into the atmosphere as exhaust, polluting the environment. One kilogram of sulfur in fuel produces 2 kg of SO_2 in the exhaust. The ratio of SO_2 to SO_3 is in the range of 95:5 in diesel vehicle exhaust. SO_x concentrations in transport and power plants' exhaust can be easily reduced by minimizing sulfur content in fuels (Gotmalm, 1992). The sulfur contents in heavy and marine diesel fuels are 2.82% and 0.94%, respectively. Annual consumption of 110 million tons of fuel releases 2.91 million tons of sulfur, which is equivalent to 5.82 million tons of SO_2 (i.e., 5.3% of the global SO_2 emissions) (USENPA, 2020). Scrubbers may reduce SO_2 content in coal power plants to 6 g/kWh.

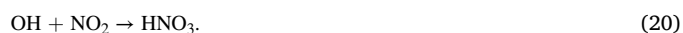
6. Ozone (O_3)

Ozone is found in two layers of the atmosphere, namely, the stratosphere and troposphere. The stratospheric ozone layer shields the earth from the sun's UV rays. The stratospheric ozone is generally termed good ozone. The ozone in the tropospheric layer of the atmosphere is harmful to humans and crops. It is a significant pollutant of air and is the leading cause of smog. It is mostly produced in the air by the interaction of free NO_x and volatile hydrocarbons. Many countries are working on lowering the free NO_x and volatile hydrocarbons in the troposphere to reduce ozone in the troposphere (Crutzen, 1988).

Ozone is formed in the troposphere by the photo dissociation of NO_2 in the presence of sunlight to NO and O. The overall reaction is as follows:



M in the above equation is any third substance to stabilize the intermediate formed by the reaction. The role of volatile hydrocarbons is the formation of NO_2 from NO of the atmosphere. The overall reaction can be written as follows:



The above reactions show the overall scenario wherein volatile organic compounds (VOC) generate NO_2 . This NO_2 is then split into NO and O, resulting in ozone, a major pollutant in the air. In addition, NO_2 is converted to NO_3 at night, which is the main cause of acid rain (Finlayson-Pitts and Pitts, 1993; Finlayson-Pitts and Pitts, 1986; Wayne, 2000). These nanoparticles will be more combustible and will minimize VOC emissions from automobile tailpipes. Many other researchers have published their results on the reduction of CO and NO_x pollution by using biodiesel and biogas fuels (EL-Seesy et al., 2018; Lenin et al., 2013; McClements and Gumus, 2016; Mehta et al., 2014; Venu and Madhavan, 2016). Some researchers advocated for the reduction of NO and NO_2 from the industries and automobiles to reduce ozone in the troposphere (Chen et al., 2019; Itaya et al., 2019; Kato et al., 2019; Zhou et al., 2019).

Catalytic reduction of GHG gases from vehicles will mature by 2030. Most vehicles will have shifted from fossil fuels to hydrogen and electric power sources, especially solar and wind energies.

Ozone can be used as a medicine to improve a body's immune system to treat HIV. It also treats infected and contagious wounds, macular degeneration, viral diseases, rheumatism, arthritis, cancer, SARS, AIDS, and circulatory and geriatric disorders. It is also used in the development of technologies, such as ozonized olive oil to be directly applied to the body, ozonized water for drinking, gas baths, or saunas. However, the use of ozone causes respiratory and heart problems, swelling of blood vessels, damage of the eardrum, etc (Biggers, 2019). Ozone builds up in the atmosphere during heat waves.

7. Plastic pollution

Plastic pollution refers to the presence of plastic-made objects and fragments in the oceans, on land, and in space. Marine species, wildlife, and the human food supply chain are adversely affected by this phenomenon. The size of the object determines whether they are micro-, meso-, or macro pieces. Plastic, a non-biodegradable material, is extremely harmful to all forms of life on earth. Every year, thousands of animals and marine species die due to plastic ingestion and entanglements. A major fraction of the global plastic waste ends up in the oceans, disturbing the marine ecosystem. The world per capita plastic consumption is 20 kg per year.

This figure varies from 28 kg in India to 109 kg in the USA. India produces 5.6 million tons of plastic waste in one year. Indus and Meghna–Brahmaputra–Ganges annually discharge 164,332 and 72,845 tons of plastic debris into the ocean. Hardly 9% of the global plastic production is recycled, outlasting everything that ends up in the soil and water bodies. According to an Arctic Ice study, every litter of sea ice contains 12,000 microplastic pieces. Scientists are concerned that the oceans will be swamped in plastics, drowning us also with them. A study showed that approximately 8 million plastic pieces go into the oceans every day. Everybody in America, on average, throws 2000 pieces of plastics in the oceans every year. Approximately 5.25 trillion macro and microplastic pieces float in the open oceans (Jesus, 2016). Nearly 80,000 tons of plastics are floating in Pacific and 269,000 tons in all oceans (Khurshid, 2019). Plastic pollution affect marine species, birds, and humans. A 40-kg plastic ball was found in the belly of a large fish. Everyone consumes 250 g of plastic annually in certain ways. Many countries are considering banning plastic bags and convert old plastics into bricks. Plastics enter the human body through air, food, and water. Our stomachs and lungs are the ultimate destinations of plastics. The ideal use of plastics is to fabricate building materials and heliostats for solar thermal power plants.

Environmentalists encourage reduce, reuse, and recycle. In the best case scenario, we throw trash in the waste bin or dumpster in the street, which is then picked up by a garbage truck and sent to the landfill site. Composting waste into soil emits green gases, and deeper burial leads to water contamination entering our air, water, and food systems. There is virtually no away, even in the animal lungs and stomachs. Birds consume plastics, which come out after their death or reach other animal stomachs. Plastics are derived from oil and recycled into packing materials. Single-use plastics are a detriment to the environment and must be recycled. They are made up of a hard-to-extract, non-renewable raw material (oil), which is polymerized through a high-energy process that includes toxic chemical add-ins and leaves harmful manufacturing by-products. Specifically, they are an environmental and public health disaster — before they are ever used. Plastic is estimated to account for 10% of all waste, and 50%–80% of all marine debris. Eight tons of plastics enter the oceans every year, and large clusters trapped in ocean gyres will remain infinitely. Municipal committees dump waste away in barrels around the town. The garbage ferments and decays there, emitting deadly fumes. We see burning, smoking, and deteriorating garbage in the streets of towns. Waters and winds bring toxic materials and smoke back into our homes. The rampant rise in litter, traffic smokes,

and industrial waste results in water and air contamination. Opportunists use contaminated waters to grow lush green vegetables to hurl poison into our local food supply chain. Plastics ultimately find their way into the human lungs and stomach via food.

8. Wind, wood and water watts

Wind and water are renewable resources that are treated as waste if not used in time. Wood is considered a renewable energy resource, yet it releases GHG emissions in the atmosphere when burnt. Dams are also clean energy resources, yet stagnant waters continue to decompose organic matter into GHG emissions. Wind and solar resources are relatively cleaner than wood and water; however, solar panels and wind turbines produce CO₂ during manufacturing. Wind power surpassed coal in 2016 and nuclear electricity in 2018. A shutdown of three coal plants had already plummeted coal power 9.2% below 26.6% in 2015. The collapse of coal compared to the wind is viewed as a milestone in power and energy history. Coal power in the energy mix is the lowest in the last 80 years (Vaughan, 2017). British electricity generation consisted of 40% coal power a few years ago, which is now 7%. The UK installed maximum wind turbines in 2016. Wind power plants did not replace all coal-driven power plants; natural gas was also used to replace coal power plants. Irish wind power capacity was 10% in 2016 and 15% in 2017 (Wilson and Staffell, 2018). British wind, solar, biomass, and hydropower plants produced 29.9 TWh electricity in 2019, more than coal, gas, and oil-fired power plants. Renewable electricity is intermittent due to its weather dependence. In August and September 2019, UK had 40% of electricity from renewable energy sources. Solar panels outperform during sunny and warmer days (Reporter, 2019). Installation of new offshore wind turbines has helped the UK eliminate fossil fuels, consisting of 39% of British electric power. It is a tipping point in the British energy transition from fossil fuels to renewable energy resources. Inauguration of new wind turbines may achieve the zero-carbon milestone (Ambrose, 2019).

Europe is phasing out coal and nuclear with solar and wind power plants. Two nuclear power plants that supply power for decades were shut down in Germany and Sweden in 2019 (Paulsson and Wilkes, 2019). The transition from fossil fuels to solar, wind, water, and wave energies is more technical than an economic barrier. Running a power grid on intermittent solar and wind power threatens reliability without massive battery backup (Basit et al., 2020; Wade, 2019). The natural cycle of sun-powered wood, wind, water, and wave energies may be expressed as number 8, as shown in Figure 9.

Finite fossil fuels on earth are a harbinger for finding new energy avenues. The United Nations Sustainable Development Goals include end of poverty, no hunger, health facilities/social well-being, basic education, gender equality, clean drinking water/sanitation facilities, cheaper clean energy, honest work and economic growths, industries, innovations and infrastructures, lesser inequality, smart cities and sustainable communities, sensible consumptions and productions, actions against climate change, marine life, wildlife, stronger institutions, and global partnerships for achieving goals. Population and industrial growth rates impose restrictions on 100% renewable energy transition. Hydro-power plays a vital role in energy and food. A river-inspired canal system along with natural river examples for food production are shown in Figure 10.

9. Waste to watts conversion

US oil fields reached peak production in the 1960s, making the western world dependent on Arab oils. The oil crisis of 1973 was rooted in the Arab embargo, and the energy crisis evolved in the wake of the Iranian revolution in 1979. Two energy crises in the 1970s bent western countries to look for alternate avenues. US energy experts started focusing on city waste to convert it into watts. The heating value of organic waste varies from 3000 to 8000 BTU/pound. Engineers initiated experiments on solid waste pyrolysis and sewerage slug anaerobic

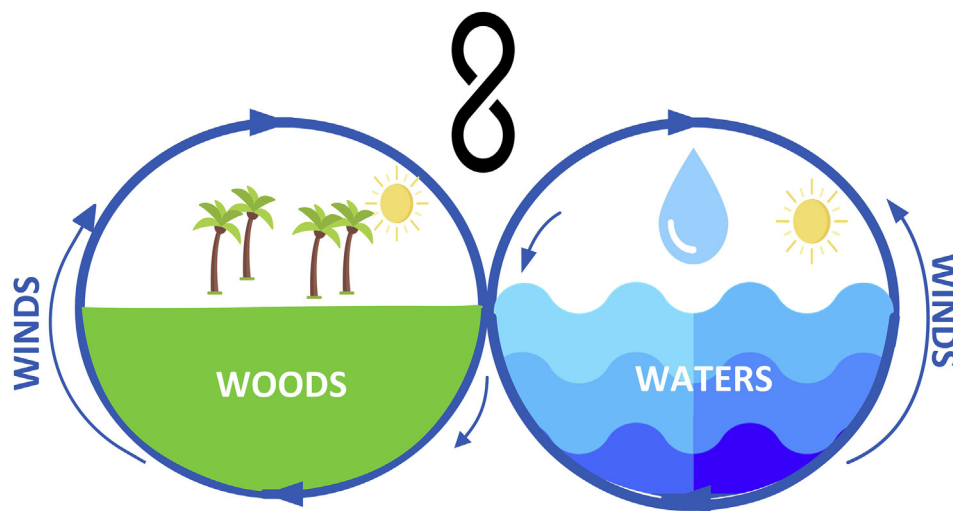


Figure 9. Sun powered wood, winds, water, and wave energies.

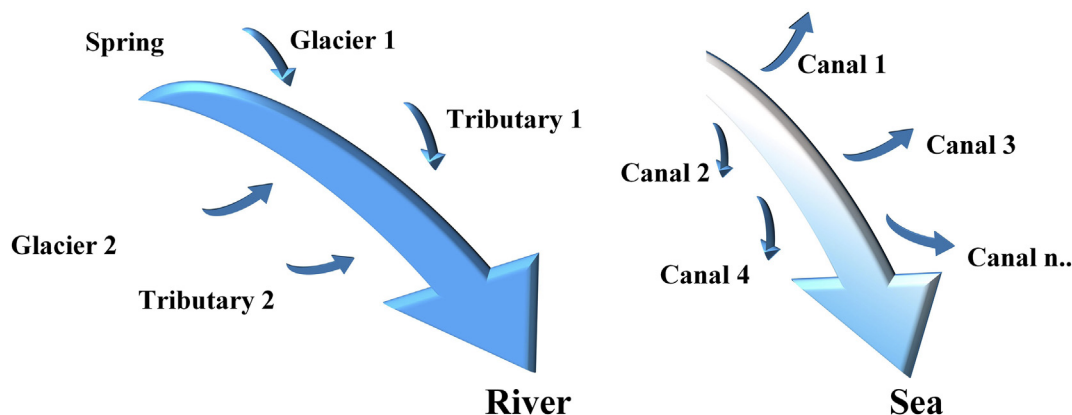


Figure 10. Nature-inspired canal network.

digestion. A few dissidents advised burning all waste along with coal in thermal plants. The city government advised workers to shift solid waste to utility plants where metal, stone, and glass pieces were filtered before burning (Hagerty and Heer, 1975).

Waste to energy (WTE) technology converts waste into electricity instead of burning fossils, reducing GHG emissions. The US Energy Policy Act endorses WTE conversion as a renewable process. These processes will significantly meet the future requirements set by net-zero carbon and waste visions. WTE conversion processes have the potential to reduce 160 million tons of annual greenhouse gas emissions. It is expected to cater 2% electricity by 2030. Prototypical WTE stack emissions consist of 65% CO₂. Currently, the US hosts 87 facilities capable of converting 90,000 tons of waste each day on average. This produces 2.3 GW of electricity that is easily accessible, making it a baseload generator (Klinghoffer et al., 2013). Moreover, these processes avoid landfill formation, which can leak into the atmosphere (Klinghoffer et al., 2013). The lifecycle of CO₂ emissions by incineration (760 °C–870 °C) is 14–35 kg of CO₂/kWh, gasification (760 °C–1537 °C) is 8 kg of CO₂/kWh, pyrolysis (649 °C–1204 °C) is 9.5 kg of CO₂/kWh, anaerobic digestion is 11 kg of CO₂/kWh, and aerobic digestion is 1–14 kg of CO₂/kWh (A et al., 2020). The incineration yields electricity at a rate of 544 kWh/ton of waste to the grid; pyrolysis produces 571 kWh/ton of municipal waste, and gasification yields 685 kWh/ton of waste. The gasification and incineration produce SO_x, NO_x, and CO_x. With gas capture, the CO₂ equivalent of incineration, gasification, and landfill account for up to 1.6, 1.07, and 2.75 kg/kWh (Brandon, 2013). Studies and surveys reveal that

a single person contributes to emitting 1 kg CO₂ and 0.5 kg waste on average (Abas et al., 2018a; Basu, 2010). High income (50%) and middle-lower income (30%) groups produce maximum waste compared with low income (3%) and upper-middle-income groups (20%). Carbon footprints depend on the energy used; co-fired carbon footprint is 775 gCO₂/kg, and biomass footprint is 230 gCO₂/kg. The electricity we can obtain from waste costs approximately 2–7 and 8 to 11 cents/kWh for wholesale and retail consumers, respectively. The carbon footprint values for waste to energy conversion (WTEC) compared with fossil fuels and traditional renewable resources are shown in Figure 11.

Scientists discovered biofuel bonanza and energy crops on stagnant waters in ponds as a result of their energy study. They used cattle dung to produce biogas, which was utilized to fuel power plants. Cattle waste became popular fuel source, and the farmers began installing digesters on their farms. Exxon/Mobil started focusing on city garbage to produce watts from waste. Although the oil and energy crisis ended in the 1980s, research into alternative energy resource continued. Energy experts began evaluating green urban solids, landfills, and farms, in addition to solar and wind power plants. They found landfills, urban solids, and farms to hold the potential of 116 PJ, 241 PT, and 1132 PT energy in the USA. They developed solid fuel cells to convert biogas into 16, 33, and 157 TWh energy reserves under waste 2 W (W2W) projects (Ma et al., 2021; Wang et al., 2020). Elsevier launched the Journal of CO₂ utilization to convert GHG emissions into value-added products.

Several reports on the conversion of CO₂ and CH₄ into fuels and fertilizers have been published (Sagir et al., 2018). The primary goal is to

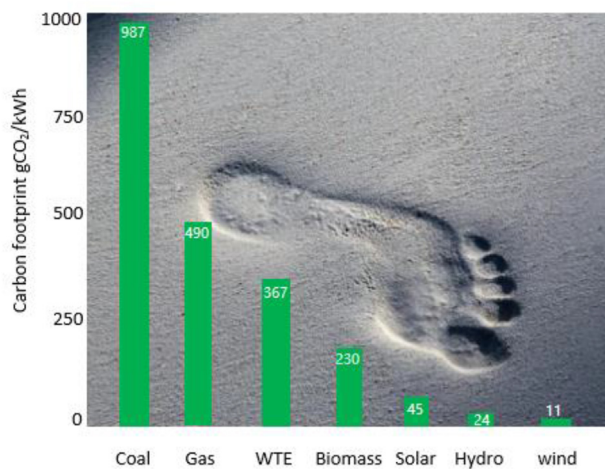


Figure 11. Carbon footprint values for various energy resources.

directly capture CO₂ from the atmosphere and store it in underground caverns or convert it into value-added products. CO_x, NO_x, and SO_x gases remain in the atmosphere for decades and centuries, just as plastics in the oceans. Natural lightning converts NO_x into nitrogen and SO_x into sulfur. The temperature in the lightning path approaches that of the sun surface or earth's core level that is high enough to break GHG emission in the air into constituent components (Ehhalt and Prather, 2001). Lightning is helping humanity in removing GHGs from the atmosphere, just as it did at the beginning of existence (Kalair et al., 2013). Lightning cleans the atmosphere at clouds levels, and the end products fall on earth as rain-drops. Lightning strikes create oxidants that react with pollutants and decompose them into less toxic forms. Lightning creates OH and HO₂ radicals, which react with pollutants. Rapid heating and cooling of air during lightning creates NO, which reacts with O₂ to form NO₂. The formation of NO_x at the level of the clouds lowers ozone pollution at the ground level. Some pollutants are also broken down by UV, causing them to react with other gases or deposit on particles. In rainwater, SO₂ may react with O₂ to form ammonium sulfate, which is an excellent fertilizer. H₂S reacts with metal oxide particles to form metal sulfides that act as catalysts in H₂SO₄ formation. HF reacts with organic matter to form compounds that are carried away by rain. Hydrocarbons are decomposed by photochemical reactions.

10. Conclusions

Air pollution affects humans, animals, plants, and energy systems. The conversion of air pollutants decelerates climate change, decreasing life and property losses. Interest-driven sustainable technologies that convert air pollutants to power, energy, and value-added products can relieve the world from air pollution and global warming crises. Air pollution-related premature deaths are increasing with climate change. Annual pollution-related deaths were 8.3 million, whereas smoking-related deaths were 8.02 million in 2017. Air pollution eliminates three times more masses compared with HIV/Aids, TB, and Malaria. Air pollution takes the life of 15 times more people than revenge murders and deadly wars. Toxic air pollution is primarily caused by vehicles and heavy industries. In the USA, air pollution is responsible for more than 40% of premature deaths, while air toxins account for 55% of pollution-related mortalities.

By this time in history, 30 July 2021, the Covid-19 virus in its various concerning forms (alpha, beta, gamma, and delta) has affected approximately 197 million people worldwide. Of these, 178 million people have been recovered, 4.2 million are dead, and the rest are recovering. Deforestation is responsible for significantly reducing the barrier between animals and humans, making humans vulnerable to virus outbreaks of animal origins. Nature had pushed fossil fuels into deeper layers

of the earth and kept bats at bay in distant jungles. Oil barons have unearthed oil, gas, coal, and shales, and proper dealers have deforested jungles to build housing societies. All diseases spread through the air, water, and food chain; hence, we keep pace in harmony with nature by sequestering carbon that we produce on a daily basis and replacing coal and gas power plants with solar and wind energy. Pollutants pollute the air, and plastics contaminate the food chain. GHG emissions remain in the atmosphere for a long time, affecting the radiation balance causing global warming. The conversion of waste into watts is a holy grail for the planet's human civilization. Waste to energy conversion technologies allow us to utilize waste heat instead of producing more electricity and GHG gases to accomplish the same task. Waste to energy conversion is the first step toward sustainable living.

Declarations

Author contribution statement

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Data availability statement

Data will be made available on request.

Declaration of Interests Statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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