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Key ingredients and recycling strategy of personal protective equipment (PPE): Towards sustainable solution for the COVID-19 like pandemics

Samarjeet Singh Siwal [a,*], Gauri Chaudhary [a], Adesh Kumar Saini [b], Harjot Kaur [a], Vipin Saini [c], Sudesh Kumar Mokhta [d], Ramesh Chand [e], U.K. Chandel [f], Graham Christie [g], Vijay Kumar Thakur [h,i,j,k,l,**]

[a] Department of Chemistry, M.M. Engineering College, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana 133207, India
[b] Department of Biotechnology, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana 133207, India
[c] Department of Pharmacy, Maharishi Markandeshwar University, Kumarhatti, Solan, Himachal Pradesh, 173229, India
[d] Department of Environment, Science & Technology, Government of Himachal Pradesh, 171001, India
[e] Department of Health and Family Welfare, Government of Himachal Pradesh, 171001, India
[f] Department of surgery, Indira Gandhi Medical College and Hospital (IGMC), Shimla, Himachal Pradesh 171001, India
[g] Institute of Biotechnology, Department of Chemical Engineering and Biotechnology, University of Cambridge, Cambridge CB2 1QT, UK
[h] Biorefining and Advanced Materials Research Center, SRUC, Kings Buildings, Edinburgh EH9 3JG, UK
[i] Enhanced Composites and Structures Center, School of Aerospace, Transport and Manufacturing, Cranfield University, Bedfordshire MK43 0AL, UK
[j] Faculty of Materials Science and Applied Chemistry Institute of Polymer Materials, Riga Technical University, P.Valdena 3/7, LV, 1048 Riga, Latvia
[k] Department of Mechanical Engineering, School of Engineering, Shiv Nadar University, Uttar Pradesh 201314, India
[l] School of Engineering, University of Petroleum & Energy Studies (UPES), Dehradun, Uttarakhand, India

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A B S T R A C T

The COVID-19 pandemic has intensified the complications of plastic trash management and disposal. The current situation of living in fear of transmission of the COVID-19 virus has further transformed our behavioural models, such as regularly using personal protective equipment (PPE) kits and single-use applications for day to day needs etc. It has been estimated that with the passage of the coronavirus epidemic every month, there is expected use of 200 billion pieces of single-use facemasks and gloves. PPE are well established now as life-saving items for medicinal specialists to stay safe through the COVID-19 pandemic. Different processes such as glycolysis, hydrogenation, aminolysis, hydrolysis, pyrolysis, and gasification are now working on finding advanced technologies to transfer waste PPE into value-added products. Here, in this article, we have discussed the recycling strategies of PPE, important components (such as medical gloves, gowns, masks & respirators and other face and eye protection) and the raw materials used in PPE kits. Further, the value addition methods to recycling the PPE kits, chemical & apparatus used in recycling and recycling components into value-added products. Finally, the biorenewable materials in PPE for textiles components have been discussed along with concluded remarks.

1. Introduction

The coronavirus (COVID-19) pandemic first commenced in Wuhan in China and was listed as a pandemic by the world health organization (WHO) in March 2020. The key symptoms in people suffering from COVID-19 infection include cough, shivering, temperature and breathing problems. The symptoms associated with different coronaviruses vary from the usual cold to more intractable infections, for example, severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), and COVID-19 (SARS-CoV-2). Therefore, to restrains, such viruses and personal protection equipment (PPE) kits have frequently been employed [1–3]. PPE that includes face covers, gloves, safety glasses, gowns, and aprons is necessary to shield individuals from being exposed to pathogens and pollutants. Healthcare workers around the globe depend upon PPE kits each day to protect themselves and hospitalized peoples from the exposure of bacteria and communicable infections. With the current high rate of infections in the second wave of COVID-19, PPE is in much more need than the pandemic's first wave.

* Corresponding author.
** Corresponding author at: Biorefining and Advanced Materials Research Center, SRUC, Kings Buildings, Edinburgh EH9 3JG, UK.
E-mail addresses: samarjeet6j1@gmail.com (S.S. Siwal), gc301@cam.ac.uk (G. Christie), Vijay.Thakur@sruc.ac.uk (V.K. Thakur).

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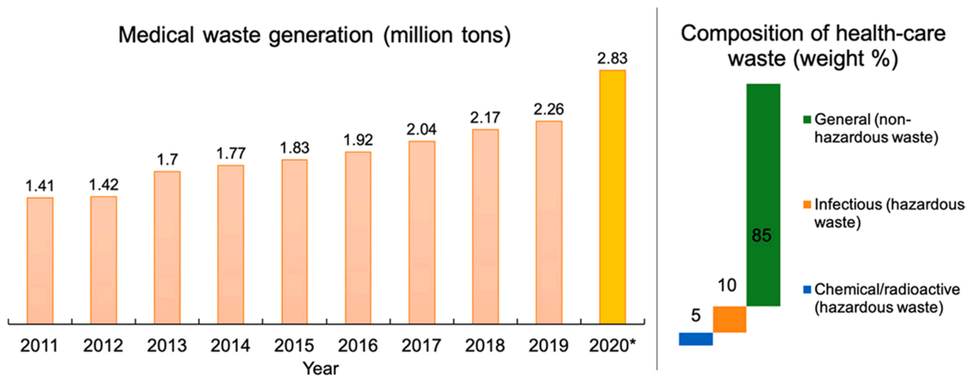

Fig. 1. Medical waste production from 2011 to 2020 and the composition of healthcare waste in China. Reprinted with permission from Ref. [10].

The current PPE need has also affected other enterprises dependence upon PPE, including structure, installation, oil and gas energy, shipping, firefighting, and food outcome. As a result, there has been unprecedented acceleration in the use of PPE [4–8]. As the predominance of COVID-19, medical waste production, such as gowns, inspection kits, plastic boxes, and syringes after discovering the COVID-19 vaccine, has been grown worldwide is a notable warning to the climate and public well-being. The number of the doubted patients, diagnosis and prescription of many sufferers, and ultimately disinfection have pointed to much communicable medical trash, mostly plastic [9]. The development within PPE production generates an equal amount into the scrap stream, combined with environmental hazards with the trash administration chain, particularly within nations including an undeveloped base. For example, China manufactures around 240 tons of pharmaceutical trash every day on top of the pandemic within China, amounting to six folds more than before the virus epidemic (Fig. 1). Some regional garbage management firms have been using portable incinerators within towns to dispose of enormous abandoned face masks, gloves, and different polluted single-use PPE [10]. Similarly, Bangkok (Thailand), Manila (Philippines), Kuala Lumpur (Malaysia), and Hanoi (Vietnam) encountered considerable advances in manufacturing around 154–280 tons/-day, additional medical garbage as the outbreak than previously. Furthermore, in other towns, Ahmedabad (India), medical waste generation increased from 550 to 600 kg/day to around 1000 kg/day throughout the lockdown [11,12].

The current literature suggests that due to COVID − 19 epidemic, the entire world population has become cautious about their wellbeing and are now taking necessary precautions to avoid infection caused by coronavirus involving PPE such as masks and gloves etc. The face mask is a primary protection measure and may shield us from the respiratory droplets generated through sneezing, cough etc., which can transmit the germ [13]. The common public have also few constraints generally used masks, like being hydrophilic, having a low melting point and lack of proper respiration. Being hydrophilic, the mask can consume the droplets to some extent, potentially raising the risk of infection. Further, they contribute to existing piles of waste that may be the additional reason for the contamination [14].

During this pandemic, the air and water conditions all around the globe have improved significantly [15]. Furthermore, according to many news experts, the sky and rivers became clean in India, reported earlier to be one of the most polluted in the world. The critical reason includes the closures of enterprises and the suspension/ holding of the work in the building industry. Still, there were some concerns about the emergent pollution and improved energy dissipation within hospitals. The energy dissipation has been primarily due to the extra hospitalization and ICU entries. Another reason for the rise within environmental footprints was that a significant amount of energy is used to construct new hospitalization facilities, design and manufacture PPE kits, food packaging, etc. [16].

As we know these days, the studies are reported involving PPE pollution in coastal sites. In this regard, Thiel et al. [17] examined the order and quantities of face respirators upon a few of the main sightseer beaches in Chile, and it has been observed that the daily collection speeds at one beach near northern-central Chile. Face protection was seen near beaches crosswise the country, including average densities of 0.006 ± 0.002 (mean $\pm$ se) face respirators m^{-2}, which are more eminent than quantities summarized at Peruvian beaches but lower than those of those at Peruvian on some Kenyan beaches. Rakib et al. [18] demonstrated PPE decomposition induced through the COVID-19 pandemic in Cox's Bazar, the most abundant natural beach within Bangladesh. Depending on area investigations, the central enterprises were brought out in every locality, classified as tourism (such as recreational movements), fishing, or tourism and fishing movements. De-la-Torre et al. [19] reported the existence and appearance of COVID-19-related PPE with the beach of the most populated town of Lima, Peru, and define the impact of the movements brought out during each examination site. In general, words, 138 PPE objects were observed in 11 coasts while 12 sampling weeks. The density was into the limit of $0–7.44–\times 10^{-4}$ PPE m^{-2}.

Zhong et al. [20] have reported on the recyclable and recyclable graphene masks, including excellent superhydrophobic and photothermal activity. This work assumes that the surface was flat and had a lower connection angle of about 110°, which leads to a slight hydrophobic surface. The superhydrophobic surfaces give a more reliable safeguard to incoming inhalation droplets. The high surface temperatures of the respirators under solar light can disinfect the surface germs. The droplets can incorporate a high connection angle to the hydrophobic body while providing the mask with a superhydrophobic surface. To support the surface properties of the PPE kits, they developed laser-induced graphene upon the exterior of surgical masks to make them superhydrophobic. To roll underneath the droplet proposed, rather than absorption of the durable superhydrophobic layer. The immediate rise of temperature over 80 °C supports deactivating the disease. The antibacterial layer was due to its photothermal characteristics applied by the Laser-induced graphene. The continuous-wave laser-induced forward transfer (CW-LIFT) has high processing heat, and nonwoven fibres have a below-melting point. Direct application can interrupt the composition of the mask, which cannot be used in CW-LIFT directly. To overcome the obstacle of hydrophobic and photothermal energy, proposed graphene film for the exterior of masks. This also has more excellent absorption characteristics than a new mask within solar energy and has long-term durability and salt denial functions. Graphene surfaced masks are simple to recover due to their excellent photothermal performance and porous constructions applied to solar steam dynamos. The ensuing solar steam production rates have also been reported to be higher than 1.13 kg/m^2 per hour below sun power. While, the health department of Canada is urging their citizens not to practice face respirators that comprise graphene because there is a possibility that it

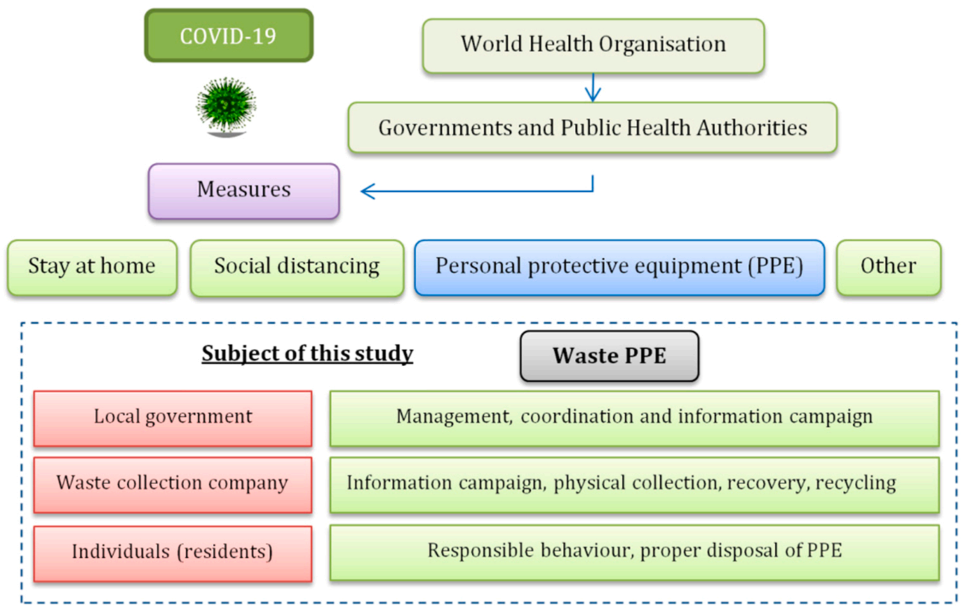

Fig. 2. COVID-19 pandemic associated trials and important rudiments. Reprinted with permission from Ref. [31].

could breathe graphene bits, which can pretend health hazards. Graphene is a novel nanocomposite (substances composed of tiny bits) described as antiviral and antibacterial characteristics. After being built conscious that masks comprising graphene have been traded with COVID-19 requirements and utilised via adults and kids in academies and daycares, the department carried a preliminary experimental evaluation. Additionally, it considers they can also have been appropriated to practice within health care environments. The health hazard to people of any generation is not apparent. Variables, like the quantity and term of appearance and the nature and properties of the graphene substance, employed, all influence the potential to breathe bits and the related health hazards. The health department has asked for data from mask makers to evaluate the possible health dangers associated with their masks that comprise graphene [21].

The recent research concluded that the individual daily productions of applied face respirators throughout the first and second waves of the pandemic within Victoria were around 104 and 160 tons [22]. The condition of Bangladesh has been explained, and predictions exhibited that a result of 3.4 billion parts of single-use facemask, hand sanitiser containers, hand gloves and biodegradable polyethene packets would be generated periodically, that will provide growth around 472.30 tons of disposable plastic garbage each day [23]. In this regard, Benson et al. [24] studied the consequence of the COVID-19 pandemic on the global plastic scrap trail. It was determined that nearly 3.4 billion single-use facemasks/face protection are dumped every day due to the COVID-19 pandemic globally. The extensive data summary does show that COVID-19 will convert the drive of the years-long global fight to decrease plastic trash contamination.

Recycling is the technique to transform waste substances into new elements and products [25]. The recyclability of a substance hinges on its capability to reacquire its characteristics within its primary state. Recycling may restrict a scrap of possibly valuable elements and decrease the destruction of new raw substances through decreasing: energy practice, air and water contamination. "Recycling" of various commodities or substances includes their reuse in the designing and manufacturing of different substances. Recycling is a critical ingredient of modern waste conversion and is the third ingredient of the "Reduce, Reuse, and Recycle" waste regime. Accordingly, recycling attempts have been towards environmental sustainability by substituting raw materials supply and redirecting waste products in the manufacturing method [26,27]. Recyclable substances comprise glass, paper, cardboard, alloy, synthetics, tires, textiles, batteries, and microelectronics. The composting or different reuse of biodegradable garbage, for example, food or field trash, is recycling. In common practice, substances to be recycled and reused are given to a household recycling centre or picked up from curbside containers, then filed, polished, and reprocessed within distinct materials designed to produce new outcomes [28–30]. Fig. 2 shows the COVID-19 pandemic associated trials and important rudiments [31].

Reestablishing single-use by reusable PPE that is sanitized between applications would decrease the quantity of trash. However, the usage of chemical sterilization can have other environmental influences. To decrease the chance of virus, technology that disinfects scraps and separation systems that decrease the mixing of contagious trash with extensive waste would also be included. Including more trash classified as non-infectious, more recycling possibilities would become possible. Because all need novel operations, support, and extra staffing, these opportunities should only be recognized through a moment of the idea when the pandemic is ended. Then, only once the sharp centre of victim medication and disease control has been overwhelmed.

Within the most stringent vision, recycling material could provide a new stock of the related materials; for example, employed office documents could be transformed into new office documents or utilized polystyrene foam within original polystyrene [32]. However, this is usually hard or highly costly (associated with delivering identical goods from feed substances or other origins), so "recycling" of various outcomes or elements includes their reuse in composing various materials (such as paperboard) preferably. A different kind of recycling is retrieving specific materials (e.g., elements in case of metals) from aggregate outputs, both due to their inherent value (for example, lead of car batteries or gold of reprinted circuit boards) or their dangerous environment. For a recycling plan to work, the production of an ample, steady stock of recyclable substances is essential. Three authoritative choices have been employed to produce such an amount, including necessary recycling assortment, box precipitate law, and protest limitations. Compulsory acquisition laws have established recycling marks toward towns to propose for, generally within the body, which a specific material rate must be turned from the town's scrap stream with an end time. The town is then accountable for operating to reach this mark [33]. Disease restriction and check dimensions comprise other projects: hand sanitation, PPE and garbage control substances. The health care people or any different workers set to guard infections by the shielding kit consists of garments. These typically consist of conventional materials

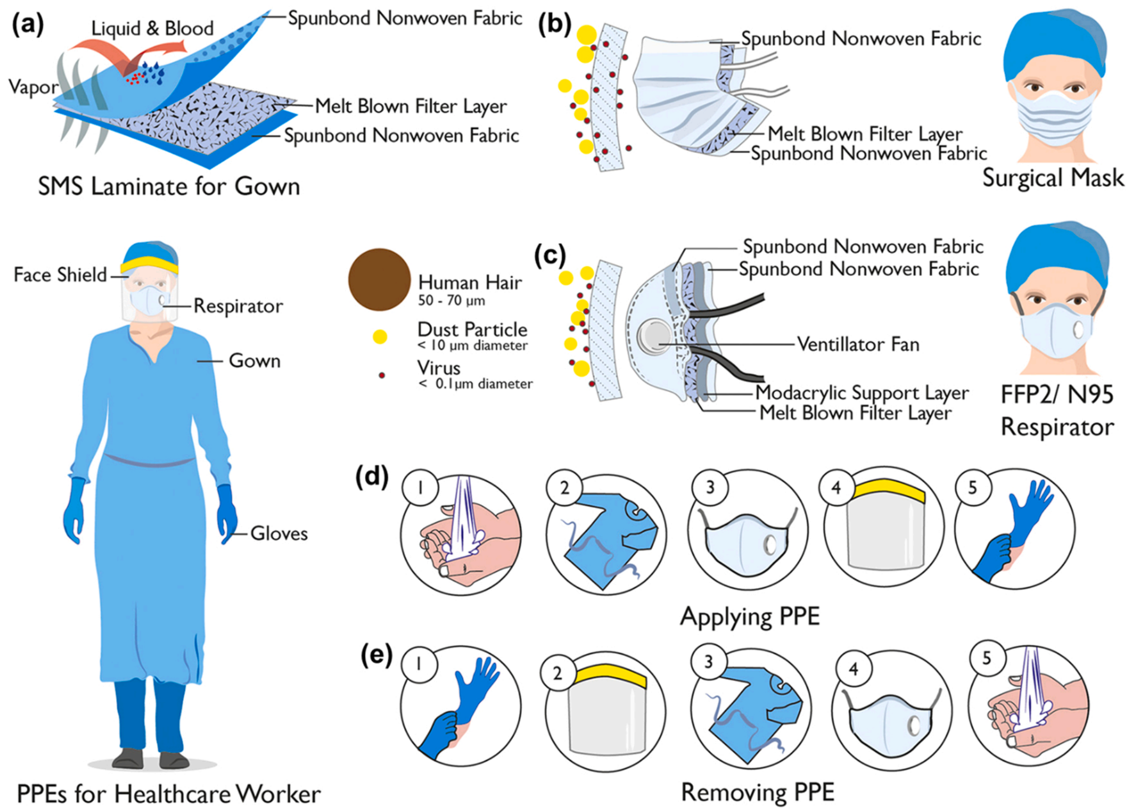

Fig. 3. PPE for healthcare workers (HCWs). (a) HCW including a reliable PPE kit. (b) A surgical mask with SMS construction guards versus more significant bits but is not capable of airborne diseases. (c) FFP2/N95 respirator gives an effective shield against airborne diseases by preventing > 95% of particles. (d) Steps to place upon PPEs for healthcare context and (e) Steps to cautiously withdraw PPEs without infection. Reprinted with permission from Ref. [53].

such as gloves, face shields and aprons. In case of blood or high airborne contaminations, this comprises a face shield, safety glasses, gloves, apron, head protection, rubber shoes [34–36]. Non-woven polypropylene constructs many parts of this, which is usually hard to reuse. However, researchers have utilized pyrolysis to recover PPE kits to develop a substance below the high temperature. The researchers observed that setting PPE within a pyrolysis thermal reactor for around one hour could transform the substance into melted biofuel. “This change will not only stop the critical after-effects to humankind and the atmosphere but also provide a reservoir of energy,” [23,37,38].

The aim and objectives of this review article are to providing such strategies that help discover and produce any method for PPE kits treatment for valuable products. Recently, the environmental implications and limited availability of non-renewable energy sources directed the core concern towards renewable energy sources. One of them is PPE kits and medical waste and its conversion to the valuable products presented in this article. Hereunder this review, the question of how to recover the product from PPE and waste is addressed. The article aims to answer the PPE and its types (what), the need for value-added products (why), the idea to provide outcome from PPE, the recovery processes (how) and strategies. Here, in this article, we have discussed the recycling strategies of PPE, important components (such as medical gloves, gowns, masks & respirators and other face and eye protection) and the raw materials used in PPE kits. Further, the value addition methods to recycling the PPE kits, chemical & apparatus used in recycling and recycling components into value-added products. Finally, the bio-renewable materials in PPE for textiles components have been discussed along with concluded remarks.

2. Recycling of personal protection equipment (PPE) kit

As lockdowns continued to exercise globally to reduce the spreading of COVID-2019, the global need for petroleum has dropped. It has also resulted in excessive production of pure synthetics from fossil fuels rather than from recycling. This price inflation and living practices that include plastic usage have also resulted in addressing plastic contamination [39–41]. WHO has noticed an increment in manufacturing the single-use PPE around 40%. If the worldwide community adheres to a disposable face mask model per day after lockdowns end, the epidemic will result in cyclical global destruction and scrap of 129 billion face covers and 65 billion gloves [42]. If the increments observed in Wuhan exist outside, the United States will produce a whole year’s medicinal rubbish value within 2 months [43].

As stated previously, a new report estimated that 129-billion face protection and 65 billion plastic gloves are used every month as we keep fighting COVID-19. Most of this kind of PPE waste goes into landfills and contributes to greenhouse gas emissions. Unfortunately, a significant amount of PPE waste is also thrown open and can be found scattered at our roads, shores, and seas, thus endangering wildlife as well [44,45].

Presently, the world is focusing on battling COVID-19; however, simultaneously, we can foresee the issues of economic crisis and ecological imbalance. Masks are the basic needs of every person during this pandemic, and consumption has immensely increased worldwide. The protection efficiency is the main criterion for the selection of any mask. One of the key points to be noticed is that it should be appropriately designed by selecting the material used for its production. The material used should be disinfectant and must not harm nature. Due to the excellent filtration efficiency, N95 and surgical masks have been reported to be more effective than reusable masks. N95 masks are better than surgical masks if we have to compare these two. Disposal masks must be treated excellently to minimize the impact of energy. Along with the PPE, the consumption of disinfectants has increased on a large scale across the world, where alcohol-based disinfectants are preferred, followed by sodium hypochlorite. The production of ethanol has extra

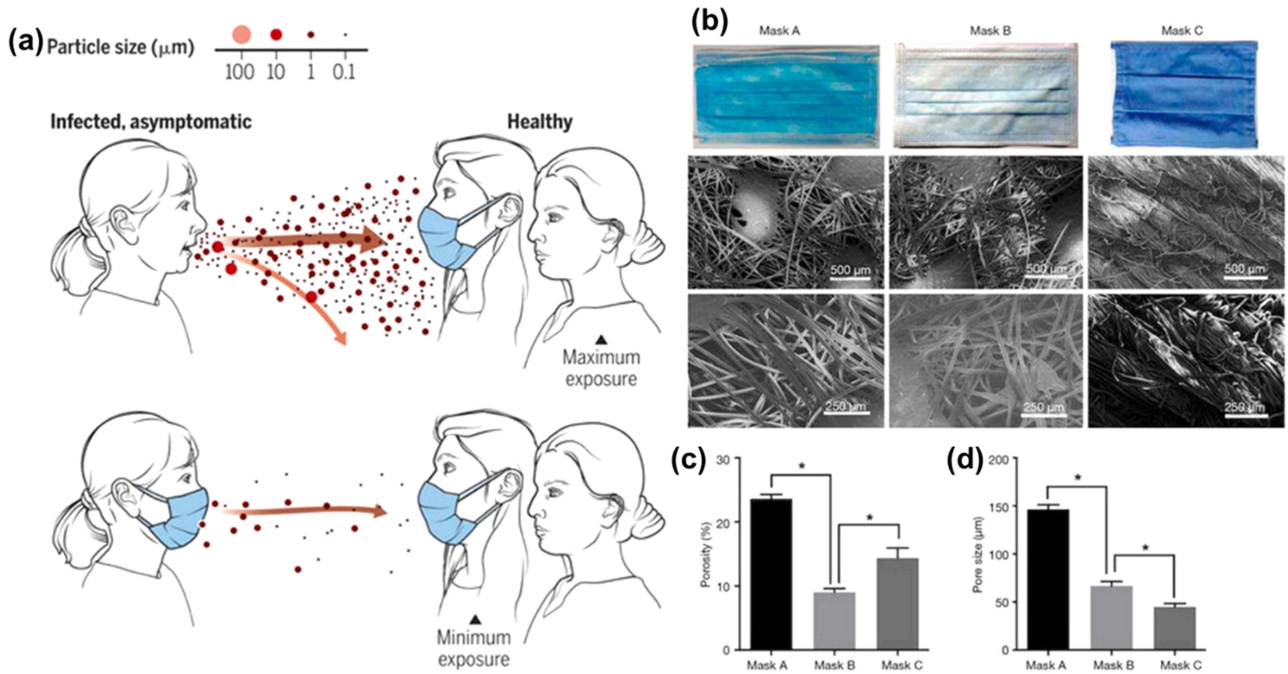

Fig. 4. (a) How face masks support decreased airborne infection. (b) SEM images displaying the fibre formation of several masks. (c) Mask sponginess. (d) Mask void dimension pattern. Reprinted with permission from Ref. [58].

energy demand and environmental issues. Still, the medical use of ethanol is also increasing rapidly [46,47].

3. Important components of personal protective equipment (PPE) kits

During the times of COVID-19, PPE kits have become a need for numerous people. In particular, doctors and pharmaceutical staff essentially need these kits, along with frontline workers, providing essential services in crises. Besides this, many people travelling via flight prefer to use PPE kits for complete protection from infection. To decrease the probability of any side effects like collapsing if improper ventilation, devices must be well equipped and supported within a neat and practical situation [48,49].

Manufacturers should continuously evaluate the workplace to blueprint if risks that need the head, eye, face, hand, or footing shield are present. If risks or the possibilities of risks are detected, employers must make sure that appropriate PPEs are selected and provided to the employers to protect from these risks. Before carrying out the work needing PPE usage, workers must understand while PPE is required, what kind is essential, how this is to be used, its boundaries, and its decent care, preservation, valuable time, and end [50–52]. Additionally, Karim et al. [53] proposed a sustainable personal protective cloth for healthcare purposes. The most typical sorts of PPE in a healthcare ecosystem are PPE kits (such as gloves, gowns, masks, goggles and face protection) (Fig. 3**a-e**). Spun-bond-melt-blown-spun-bond (SMS) laminate cloth utilized to a disposable disinfectant apron. It shields from fluid and blood at the same time sustaining aid.

3.1. Medical Gloves

Gloves shield people from infections while directly in contact with possibly contagious substances or infected exteriors. Medicinal gloves are parts of PPE utilized to guard the wearer and/or the sufferer from contamination or disease scope during preventive trials and investigations. Medicinal gloves are a perfect example of a virus restriction approach [54].

However, medical gloves are also single-use and include testing gloves, operational gloves, and medicinal gloves for controlling chemotherapy tools (chemotherapy gloves). The FDA classifies these gloves as Group I possessed medical tools which need 510(k) premarket information. The FDA studies approve these tools to meet performance standards, such as drop protection, tear resistance, and biocompatibility.

3.2. Gowns

Gowns assist to shield one from the infection of apparel, including potentially transmissible substances. They are practiced to shield the wearer from the range of disease or sickness if the wearer gets in touch with possibly communicable liquid and solid substance. They may also assist stop the gown wearer from transporting microorganisms, injuring exposed cases, such as the reduced shielded operations. Gowns are one of the essential components of an overall epidemic control approach.

3.3. Mask and respirators

Surgical mask assists in shielding the nose and mouth from splattered body fluids, and respirators purify the air before breathing it. N95 respirators and medical facades are parts of PPE practiced protecting the wearer from aerial elements and liquid poisoning the surface. It is essential to understand that the optimal approach to stop airborne communication is to practice various interferences from crosswise authorities' hierarchy, not only PPE individual [55].

The Centers for Disease Control and Prevention (CDC) do not suggest that the overall society uses N95 respirators to defend against lung viruses, such as COVID-19. These should be kept towards hospitals professionals and other medicinal first respondents, as suggested through the current CDC administration. The CDC advises that ordinary people should practice/use manageable cloth face covers while within a public context to reduce the virus's scope since this will help somebody who can have the infection and do not understand it from spreading these over others.

A *medical respirator* is a slack, one-time tool that produces a substantial obstacle among the user's mouth and nose and possible toxins within the natural environment. Surgical masks are labelled as medical, separation, dental or medicinal style masks. They can appear by or shear

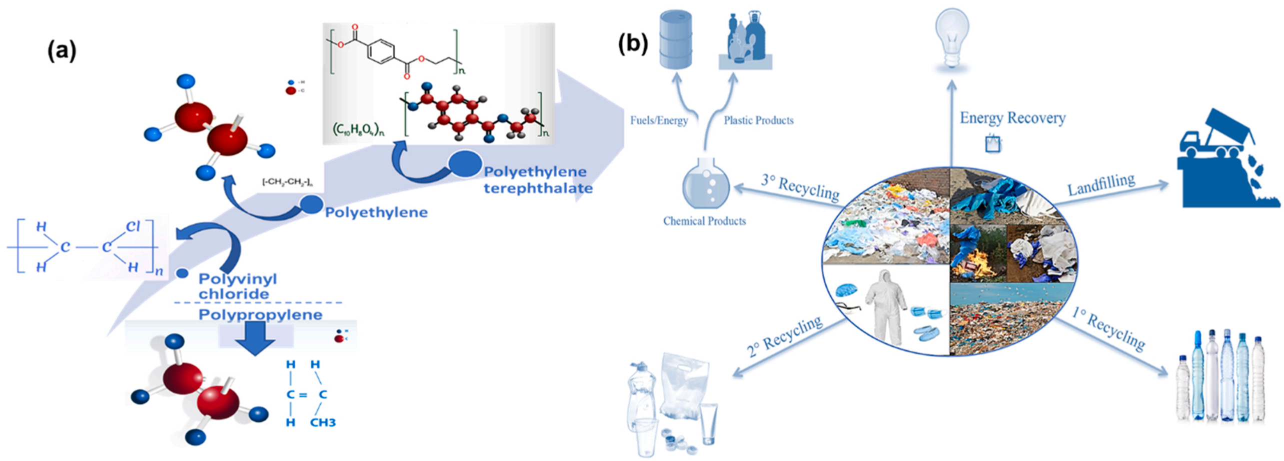

Fig. 5. (a) Important raw materials that have been used for PPE kits and (b) common fates for current plastic waste.

of face protection. These are usually applied as a face shield, although not all face masks are classified as surgical masks [56]. Several widths and the capability built by surgical masks to shield one from interaction by fluids. These characteristics can also influence how quickly one can move within the face cover and fit the surgical cover shields. If used correctly, a surgical mask is intended to block large-unit dewdrops, sprigs, or spatter containing pathogens (germs and microorganisms), preventing them from entering the mouth and nose. Surgical masks can also further decrease weathering of spit and breathing issues to others. As a surgical mask can help prevent spatters and large-particle dewdrops, a facemask does not separate or block microscopic bits within the air, spread through colds, sneezing, or specific medicinal systems. Surgical masks also do not give absolute assurance from viruses and other infections because of the slack fit between the mask's exterior and face. It is advised that if the mask is broken, dirtied, or exhaled via mask becomes hard; one should take away the facemask, dump it carefully, and substitute it with a fresh one. To carefully dump the mask, it should be kept in a synthetic container and then thrown into the garbage, followed by rinsing hands after touching the handled mask [57].

Respiratory dewdrops and aerosols (Fig. 4**(a)**) are the primary infection mode of COVID-19, with asymptomatic people spreading the germ unknowingly whilst inhaling or conversing. The dimension of these dewdrops changes the process of disease. Large dewdrops (>20 μm) will befall upon things calmer than minor dewdrops owing to gravity, while tiny dewdrops (<5–10 μm) will vanish midair leaving for airborne spread. Dewdrops of 1 μm in proportions were recorded to stay airborne for over 12 h by more coughs or sneezes carrying these elements over 20 feet. A current study reported based the separation performance on three different masks, permeability and airflow protection, Mask A with one mesh shade, Mask B besides two sieves and a reusable fabric Mask C. Here, Mask B proposed as to give the most reliable separation due to its lowermost sponginess and maximum filtering effectiveness. Mask A controlled large voids, leading to compact filtration efficiency, while Mask C had the maximum airflow protection, pointing to breathing complications (Fig. 4**(b-d))** [58].

An **N95 respirator** is a respiratory shielding tool designed to deliver a very sticky facemask and effective airborne particles' purification. For making, a tie nearby the nose and mouth intended the sides of the respirator. Surgical N95 respirators are usually utilized within healthcare environments and are a subcategory of N95 Filtering Facepiece Respirators (FFRs), frequently assigned as N95s [59,60].

The comparisons between surgical masks and medical N95s are:

- They are used in fluid protection, purification efficacy (particulate separation effectiveness and microbial separation capability), inflammability and biocompatibility.
- They should not be used in standard or secondhand.

3.4. Other face and eye protection

Spectacles further shield the eyes from droplets. Face protection gives a splatter shield to the facial surface, eyes, nose, and mouth. Face protection appears in different modes, but all give a transparent plastic block that shields the face. For maximum shield, the protection should continue under the jaw anteriorly, to the ears alongside, and there would be no opened hole among the forehead and the protection's headpiece [61]. Faceguards need no unique substances towards incorporation and composition materials may be repurposed relatively quickly. Face shields allow several merits They are easy wearing, protecting the entrances of the viral approach, and reducing autoinoculation potential by stopping the wearer from touching their face [62]. Most face protection seems to significantly decrease the quantity of breath susceptibility to a disease germ. During a simulation investigation, face guards were found near 96% to overcome acute viral vulnerability when used with a simulated wellness care person 18 in. of a cold. Still, over the next 30 min, the shielding impact surpassed 80%, and face protection formed 68% of tiny bit aerosols, which is not estimated to be an imperative form of transportation of SARS-CoV-2 [63]. Based on the recent study approved physical distancing range of 6 feet, face protection decreased breathed germ by 92%, comparable to distancing only, reinforcing the significance of physical isolation in inhibiting viral respiratory viruses. However, no investigations have assessed the results or possible advantages of face protection upon origin handle, i.e., comprising a sneeze or cold while covered with asymptomatic or symptomatic infected bodies [64]. Eye shields may provide further advantages. A thorough examination of hazard constituents for healthcare professional attainment of SARS, with multivariate comprehensive approximating equation logistic regression patterns, classified unsafe eye communication by body liquors being a self-governing hazard constituent toward contamination [65]. In a study of US healthcare departments where SARS-CoV-1-infected cases were assessed, 70% of workers stated unusual vulnerability to cases without using some level of eye shield, and none got a disease [66].

Though conjunctivitis has been defined within a few cases by COVID-19 and its other symptoms [67], emerging proof recommends that coronavirus insert the host through the conjunctival way [68]. Conjunctiva can be a possible entrance to the virus [69] because it is straightly exhibited to extraocular pathogens, and the film of the visual exterior and uppermost respiratory region are combined through the nasolacrimal channel. In addition, SARS-CoV-2 was measurable into the various nasolacrimal mode–associated networks, including the conjunctiva, lacrimal organ, nasal decay, and neck, therefore confirming the

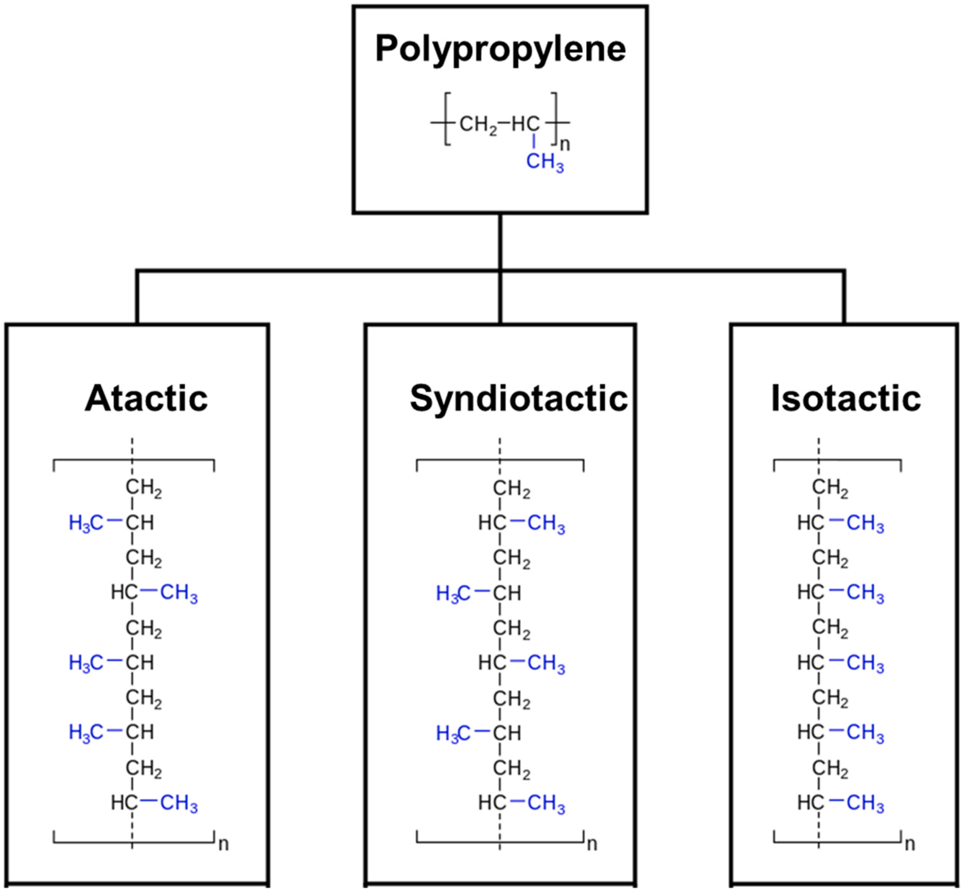

Fig. 6. Shows that PP can be sectioned in atactic, syndiotactic and isotactic.

anatomical link among visual mucosa and the respiratory region. Lastly, macaques were reported to be responsive to SARS-CoV-2 germ by the conjunctival way and advanced toward lung contagions recommending the vital interest of eye disease [70].

4. Important raw materials used in PPE kits

Polymers, textiles, latex, or natural commodities such as cloth generally make PPE. For example, the substances utilized in face protection can be a twisted fabric, cotton including elastic bands, or a textile strap to holding over the face [71,72]. Similarly, the most ordinarily practiced gloves can be constructed from latex or polyethene foil. The production materials are comparatively simple to reuse. However, the PPE components are comparatively small and lightweight, and they can be readily blended with another scrap. A different potential design of waste PPE procedure is energy retrieval through incineration. The calorific value of medicinal waste covers 19–24 MJ/kg, and polymers, with plastics, are 35–44 MJ/kg [73,74]. The essential raw materials that have been used for PPE kits and common fates for current plastic waste are shown in Fig. 5 (a, b).

4.1. Polyvinyl chloride

PVC is globally the third most generally created artificial plastic polymer (next to polyethene and polypropylene). PVC occurs in two primary modes: hard and flexible. The rigid PVC pattern has been employed to produce pipe and outline purposes, for example, doors and windows [75]. It is also utilized to manufacture jars, non-food packaging, food-wrapping films, and tags (e.g., bank or company boards). It can be changed to softer and adaptable with the extension of plasticizers (the commonly utilized phthalates). It is also employed within pipes, electrical wire protectors, artificial leather, carpet, signage, phonograph recordings, inflatable commodities, and various purposes to substitute rubber [76]. Together with cloth or linen, it is practiced within the generation of the canvas.

Here in the case of PPE kits, the gloves manufacturers use natural rubber PVC and polyurethane to prepare for the protection by COVID-19. The prepared gloves are generally soft, dust-free, non-sticky, and are employed to stop/restrict the transportation of disease/germ [77].

4.2. . Polyethene or polythene

Polyethene (PE) is a well-known plastic in practice now. This is a linear, human-made, addition, homo-polymer, essentially utilized toward packaging (plastic cases, plastic sheets, boxes, bottles, etc.) and other applications. Since 2017, above 100 million tons of PE resins are produced annually, making them 34% of the entire plastics business [78]. This may be low density or high-density polyethylene. Low-density polyethene (LDPE) is prepared via employing high force (1–5k atm) and high heat (520 K), whereas high-density PE (HDPE) is prepared via utilizing low force (6–7 atm) and low heat (333–343 K). PE is ordinarily thermoplastic; however, this may be transformed to fit thermosetting somewhat of cross-linked PE [79]. The gown that comprises the full-body (from top to bottom-the disposable gown) originates from polyester polypropylene (PP), PE. The reusable gown is manufactured with polyester/cotton mixtures. These substances are applied because they are water-protected. The gown is employed to guard both the sufferer and caregivers from the transference of bacteria, germs, infection etc.

4.3. . Polypropylene

Polypropylene (PP) is a thermoplastic polymer utilized within a broad class of commodity polymeric materials. This is prepared through chain-growth polymerization of the propylene monomer and is crystalline and non-polar. The characteristics are comparable to polyethene, but it is partially more rigid and higher temperature resistant. Bio-PP is the bio-based equivalent of PP and is currently being explored for several applications. PP is the second-most generally manufactured plastic material (next to polyethene). In 2019, the global business toward PP was $126.03 billion. This material's trades are projected to increase at a rate of 5.8% per year by 2021 [80,81].

Jain et al. [82] suggested PP's construction method in three separate stereo particular arrangements: (i) Isotactic: The arrangement of all the central carbons, having methyl compound, is the same. All the methyl groups are near over the plane or under the plane. (ii) Syndiotactic: The arrangement of central carbons is comparable over each other; the methyl groups exist alternately, one over the plane and subsequent under the plane. (iii) Atactic: The arrangement of central carbons has no consistency; the methyl groups are periodically at both edges. Fig. 6 shows the arrangement of subdivision of PP in atactic, syndiotactic and isotactic.

Regular N95 masks contain separation substances made of electrostatic nonwoven PP fibres semi-hard, lightweight, and fatigue-defiant. The semi-rigid composition can also affect the 3D printed parts' significantly via deformity against cooling, producing a complex 3D printing product. Extrusion 3D printing was employed to develop a 3D printable thermoplastic elastomeric element from a mixture of PP and styrene-(ethylene-butylene)-styrene (SEBS). This amalgam gives more excellent printability and versatility to the N95 mask pattern. SEBS is a polymeric elastomer with low refining heat and joint deformity throughout extrusion [83]. Therefore, the PP/SEBS blending could develop the adaptability of 3D printed N95 respirators. Furthermore, managing the thermoplastic elastomer proportion ensures modifying the elasticity and resiliency of the 3D typical substance for better-sized respirators. 3D melt electrospinning typography may also formulate PP microfibers besides constant layering to get a 3D form correctly [84].

4.4. . Polyethene terephthalate

Poly (ethylene terephthalate) (PET) is the well-known thermoplastic polymer resin of the polyester group and is employed in fibres toward apparel, vessels during fluids and foods, thermoforming to production, and in unification including glass fibre for manufacturing resins. The mainstream of the world's PET generation is concerning plastic fibres (over 60%), with container products considering around 30% of the international market [85]. Polyester accounts for around 18% of world polymer generation and is the fourth-well-designed polymer next to PE, PP and PVC. PET is synthesized through the polymerization of ethylene terephthalate and is generally reused, symbolizing "1" due to its resin identification code (RIC) [86].

There is increasing concern within thermolysis and catalytic polymer degeneration to produce different fuel portions of polymer trash. Pyrolysis is one of the most excellent techniques for processing a significant amount of petroleum stocks and shielding the ecosystem by defining non-degradable scrap volume [87]. Pyrolysis of scrap plastics is a preferred process because of the high conversion rates within the oil that may be collected. The gaseous outcomes were originating from the pyrolysis method by high caloric value, which was applied as fuel. Recycling through pyrolysis has excellent potential concerning heterogeneous scrap elements that cannot be economically isolated. Significant work has been carried on the pyrolysis of polymers', and some researchers have proposed the pyrolytic reprocessing of plastics into monomers and fuels. The most conventional plastics, e.g., PE and PP, do not produce high yields of monomers but preferably a composite of several distinct hydrocarbons, including symmetries depending upon the method forms (mainly heat and composite) [88,89]. In general, it is not feasible to separate an individual compound or a portion from those combined hydrocarbons or oxygenated composites obtained by other polymers. The typical upfront utilization towards the entire outcome stream is the usage of fuel. Thermal transformation of synthetics, mutually pyrolysis and gasification, has been well investigated, and industrial methods have been revealed to transform scrap plastics into fuels. The inferior applications concerning mixed-plastic recycled substances have directed the investigation in substitutive methods toward plastics recovery. The methods recommended for plastic scrap pyrolysis are adaptable and can use mixed plastics and composites, including remaining substances (e.g., wood and agroforest scraps and tire-derived fuel). This can also work auto thermally below a measured O_2-content. The application of acid catalysts within the pyrolysis reactor efficiently reduces the temperature needed for breaking and transforming product configuration. This second goal is also achieved by the catalytic improvement of the updraft pyrolysis produce stream [82].

Therefore, by operating the polymers on raised heat, we can decompose them and get liquids (biofuels), gases and solid remaining (hydrocarbons). The initial energy wastes can be decreased by substituting this from the biofuels accomplished with scrap plastics' processing [90,91]. Furthermore, the gases captured have excellent calorific contents and multiple directions applications. The two primary applications assumed for PPE kits can be practised, i.e., concerning wellness care (shield) and biofuels production (in climate protection). It is both beneficial to human beings and the atmosphere.

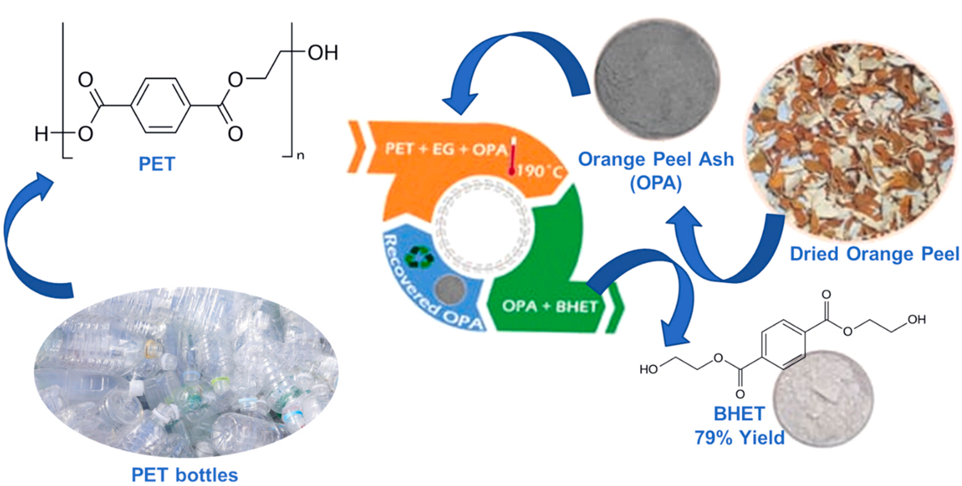

Fig. 7. Outline of the glycolysis of PET by utilizing biomass-waste derived recyclable heterogeneous catalyst. Reprinted with permission from Ref. [93].

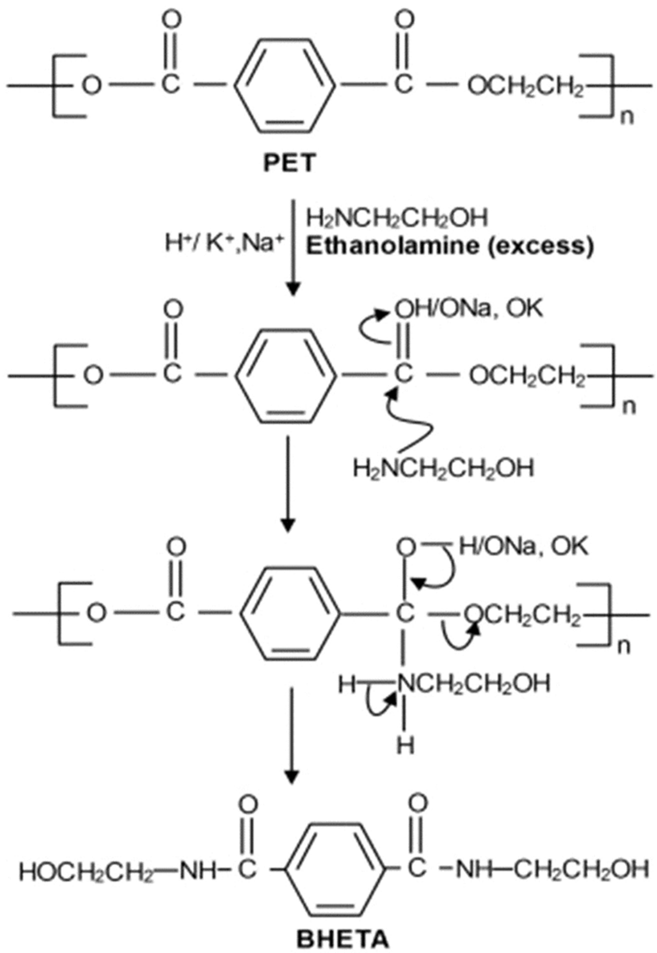

Fig. 8. Aminolysis of PET. Reprinted with permission from Ref. [110].

5. Value addition methods to recycling the PPE kits into value-added products

Now, polymer-recycling methods are an essential responsibility because of the vast number of produced wastes. Recently, different kinds of plastics are being used throughout the globe. Massive plastic quantities are employed within packing sheets, wrapping substances, buying and trash bags, fluid vessels, toys, household, manufacturing, and construction substances [92]. Due to plastic business development, polymer-recycling methods are among the most productive research subjects. Plastics may be transformed into their established compounds through catalytic/non-catalytic chemical processing or thermal methods to control the plastics more efficiently. The outcomes of chemical treatment alter the chemical composition of the plastic substances. This includes different methods that occur in the transformation of plastic scrap within value valuable goods. Few approaches are - glycolysis [93, 94], hydrogenation [95,96], aminolysis [97,98], hydrolysis [99], pyrolysis [100,101] and gasification to name a few [102,103].

5.1. Glycolysis

Glycolysis is a molecular depolymerization method for trans-esterification among PET ester groups and a diol [104]. Simón et al. [105] have industrialized a glycolysis method of standard resilient PU foams to retrieve the natural polyol. The method is split-stage glycolysis. The retrieved polyol, partly not pure, essentially constitutes the top stage and the base one with plenty of glycols used during the trans-esterification reaction and glycolysis derivatives, such as carbamates and aromatic amines. There are numerous discoveries associated with standard stretchy polyurethane foams, including polyether polyols [106, 107].

Fuentes et al. [108] have reported on the catalytic glycolysis of PET utilizing zinc and cobalt oxides recovered from used batteries. Also carried out a schematic study on the glycolysis of PET utilizing zinc and cobalt oxides recovered from used batteries. SEM was used to examine the morphology of the particles. It was reported that RZnO particles might be correlated by hexagonal patterns, while the RCoO bits are filamentous. Fig. 7 shows the schematic of the glycolysis of PET utilizing biomass-waste derived recyclable heterogeneous catalyst [93].

5.2. Hydrogenation

Hydrogenation of plastics is a possible option for cracking down the polymer series. Compared to processing without hydrogen, hydrogenation influences extremely saturated products' production, bypassing olefins in the liquid portions, favouring their application as fuels without additional processing. Furthermore, hydrogenation favours the elimination of heteroatoms, such as chlorine, nitrogen, and sulphur, into volatile composites. However, hydrogenation allows many disadvantages, principally owing to hydrogen's value and the requirement to work below high pressure.

5.3. Aminolysis

The aminolysis of PET produces TPA diamides, identified as bis (2-hydroxy ethylene) terephthalamide (BHETA), as displayed within Fig. 8. There are not many available articles about the application of this method for industrial usage in PET reprocessing. It is understood that incomplete aminolysis involves its utilization during the development of PET characteristics into the production of fibres, including established recycling characteristics [109]. In most of the explained PET aminolysis methods, the polymer has been reported in the arrangement of powder or fibres. This reaction has been carried out by utilizing primary amine aqueous solutions, methylamine, ethylamine, and ethanolamine, within the heat between 20 and 100 °C. Anhydrous *n*-butylamine was used as an aminolytic representative on the heat of 21 °C [110].

5.4. Hydrolysis

The alkaline hydrolysis method is the reaction of PET with water to crack down the polyester series within terephthalic acid (TPA) and ethylene glycol (EG) by an aqueous suspension of sodium hydroxide [111]. The massive development in post-user PET plastic scrap production and the fast-increasing promises has resulted in a constraining requirement towards effective recycling methods, such as chemical depolymerization. PET sheets were hydrolyzed into an aqueous alkaline solution in the absence of a catalyst on aerial pressure to produce disodium terephthalate (Na_2TP) salt and EG. Later, the solution was acidified to convert the Na_2TP salt into a TPA monomer, depending upon the chemical reaction displayed within Fig. 9(a). Fig. 9(b) demonstrated the laboratory set-up of PET alkaline hydrolysis [112].

5.5. Pyrolysis

The processing choices for transforming scrap plastics into valuable products are dominated by mechanical reprocessing (99%), and the remaining 1% is recovered through thermochemical recovery. Mechanical reprocessing include classifying, tearing, cleaning, drying, and pelletizing the plastic to provide recycled materials. The method preserves the plastic polymer's molecular composition, and the recovered components may be utilized to design different plastic commodities, e.g., garden furniture, shoes, trash containers, automotive pieces, etc. On the other hand, pyrolysis is generally applied to transform organic substances within a solid residue, including ash and carbon, minute amounts of liquid and gases. On the other side, extreme pyrolysis yields

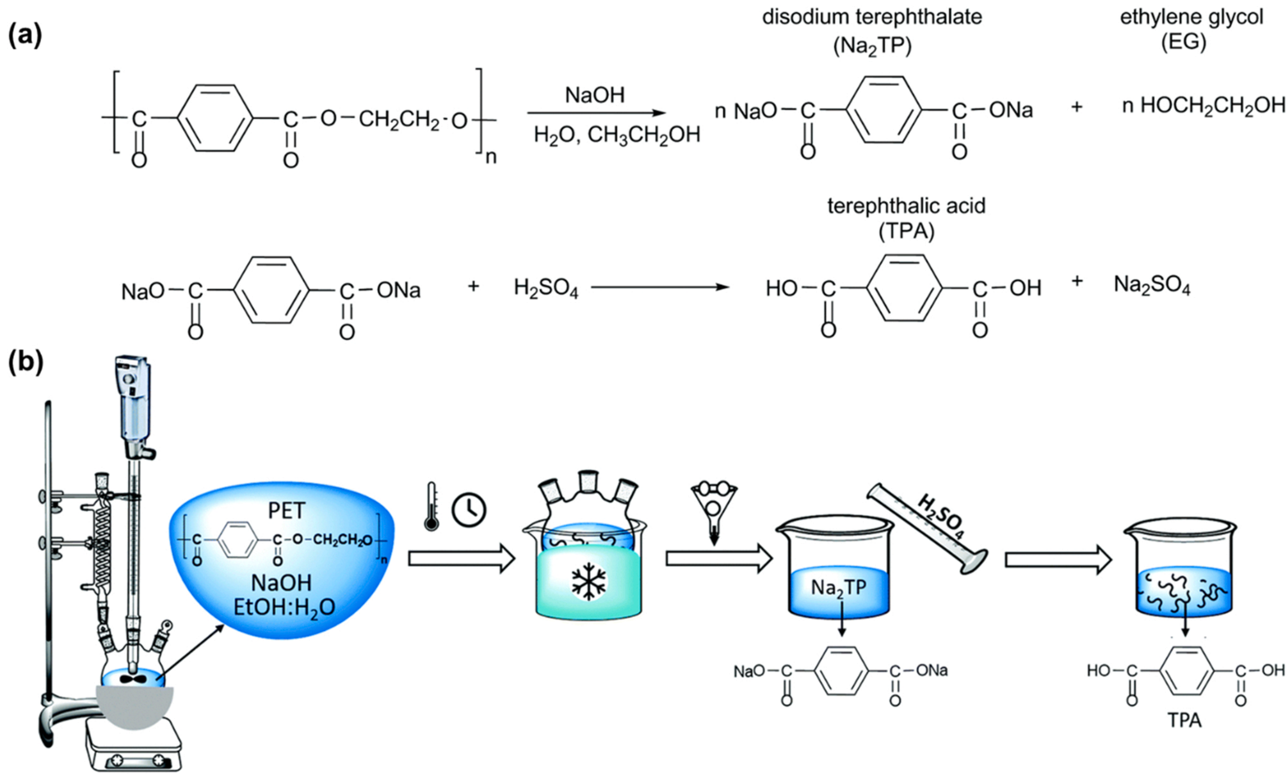

Fig. 9. (a) Alkaline hydrolysis of PET with NaOH, EtOH and water. (b) Laboratory arrangement of PET alkaline hydrolysis. Reprinted with permission from Ref. [112].

carbon as the excess and the method is named carbonization. Unlike high-temperature methods such as hydrolysis and combustion, pyrolysis does not include water, oxygen or other reagents [113,114]. Though it is functionally impossible to complete an oxygen-free atmosphere, a small quantity of oxidation perpetually transpires in each pyrolysis operation [115].

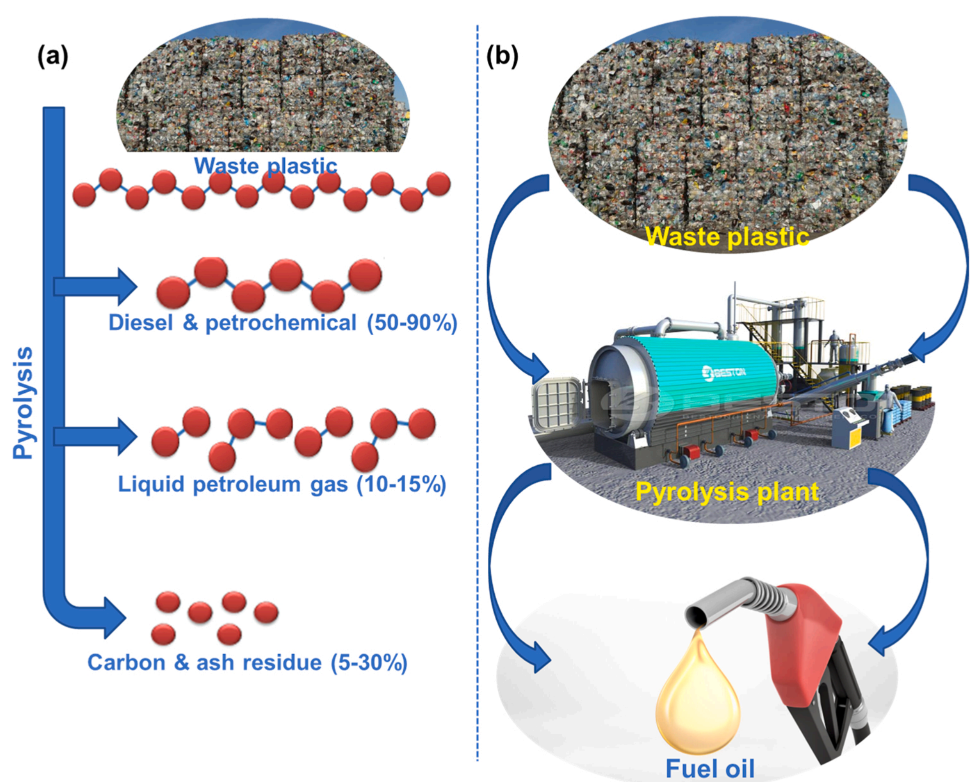

Fig. 10. (a) Temperature effects upon pyrolysis procedure and (b) construction of waste plastic to bio-oil.

Table 1
Ranges of key working factors for pyrolysis procedures. Reprinted with permission from Refs. [123,124].

Factors	Conventional Pyrolysis	Quick Pyrolysis	Spark Pyrolysis
Temperature (K)	550–950	850–1250	1050–1300
Heating rate (K/s)	0.1–1.0	10–200	more than 1000
Particle size (mm)	5–50	less than 1	less than 0.2
Solid residence time (s)	450–550	0.5 – 10	less than 0.5
Main product (s)	Biochar	Bio-oil/syngas	Bio-oil

Through pyrolysis and gasification, thermochemical recycling aims to produce more critical, valuable products, for example, petroleum's, gasoline, syngas, etc. [116]. Pyrolysis is one example of such raw material reprocessing method, where the plastic is thermally degenerated on medium heat (~ 500 °C) without oxygen to give lower molecular weight particles that can be compressed to create an oil and gas generation. There have been numerous studies upon the administration of trash plastics comprised of pyrolysis [117,118]. The plastics located within municipal solid waste (MSW) essentially contain thermoplastics and different types of plastics. Pyrolysis of these thermoplastics provides gas and oil/wax goods where the hydrocarbon formation depends upon the polymer's fundamental composition [119]. During pyrolysis, the object's units are constrained on elevated temperatures reaching very high molecular oscillations. At certain high molecular waves, every particle within the object is expanded and moved to such an intensity that particles begin cracking down within tinier particles. Aragaw and Mekonnen [120] investigated the plastics contamination warnings owing to COVID-19 and its potential reduction methods: a waste-to-energy transformation through pyrolysis. Approximately 129 billion face respirators and 65 billion plastic gloves each month are applied and distributed globally. The investigation points out the polymer nature of face respirators and gloves and sustainable plastic trash administration alternatives. The pyrolysis of the PPE kit may be arranged into a sealed thermal reactor within 300–400 °C for 60 min, which will transform the PP into liquid fuels. This regeneration will stop the harsh consequences to humankind and the atmosphere and provide a reservoir of energy. Therefore, the difficulties of PPE scrap supervision and improving energy needs could be discussed concurrently through producing fluid fuel by PPE kits. The liquid fuel originated from plastics is neat and have fuel characteristics comparable to fossil combustibles [82]. The disposable respirator is produced by several aggregates, obtaining it challenging to be reused. In this regard, Jung and co-workers [121] suggested an environmentally favourable disposal method, concurrently producing marketable fuels by the face respirator. Toward this point, a CO_2-assisted thermo-chemical method was conducted.

Fig. 10(a, b) shows the temperature effects upon pyrolysis procedure and construction of waste plastic to bio-oil. The most straightforward case of pyrolysis is food cooking. While the temperature rises, the cooked food leads to more leading molecular fluctuations and the collapse of more extensive composite particles within tinier and easy particles. After making, larger food particles are pyrolyzed within tinier in simpler particles that are simple to digest.

The pyrolysis method depends on the working circumstances divided into three subcategories: conventional, fast, and flash pyrolysis. Table 1 presents the scales concerning the foremost driving parameters during pyrolysis methods. This state allows the generation of compact, fluid, and volatile pyrolysis results in essential divisions. Pre-pyrolysis describes the initial step of biomass breakdown that happens within 395, and 475 K. By this design, any inner rearrangement, such as water removal, bond wreckage, and free radicals, includes the presence of free radicals development like carbonyl, carboxyl, and hydroperoxide groups hold the position [122].

Table 2
Gasification progression essentials with their merits and demerits. Reprinted with permission from Ref. [130].

Procedure rudiments	**Merits and demerits**
Gasifier	Categories of reactor: • **Fixed bed**: Downdraft and updraft are fit for temporary employment and raw materials with low gaseous material and high ash, including excellent moisture contents. • **Fluidized bed**: Bubbling and circulating beds are fit for the wide-scale product, homogenous dispersion of biomass scrap, including heat, uniform mixing, and low tar generation. • **Entrained flow**: Beneficial to an extensive section, helpful to coal gasification owing to high heat and low residence period. Not fit for biomass owing to high moisture, including robust content into biomass.
Gasifying agent	The different gasification agents including oxygen, air, steam besides combinations of: • **Air:** Helpful and cost-effective to small and lab-scale, the difficulty of high N_2 content including the lower heating value of fumes, not fit for CH_4 generation. • **Oxygen:** It is efficient for an extensive range but expensive for a small range, with no N_2 content obstacle, including eliminating side reaction. • **Steam:** Beneficial for H_2 generation, no N_2 dilution obstacle, expertise in the elimination of extra steam, cost-effective for both short and extensive range.
Catalyst	Three kinds of substances are applied: • **Dolomite:** Cost-effective, expertise in distribution, beneficial to tar conversion, including CO_2 adsorption. The difficulty of thermal resistance in higher heat and fluidized state. • **Alkali and Alkaline earth material:** It is suitable for tar conversion, good variety of produce gas-based, excellent stability of coke removal. It has the limitation of huge price, accumulation at high heat, blockage, no improvement, and high ash generation. • **Nickel**: General and economic catalysts suitable for tar conversion, including higher H_2 content. It has a limitation in short active time, no recovery, and removal of coke at the catalyst.

The next step of a stable breakdown matches the primary pyrolysis method. It continues, including a tremendous rate and guides towards the production concerning the pyrolysis goods. During this step, the char decays at a prolonged rate and carbon-enrich residual stable arrangements.

5.5.1. Advantages of pyrolysis

The essential advantages of pyrolysis include the following:

- It is an accessible, economical technology for treating a broad category of raw materials.
- It decreases scrap belonging to landfills and greenhouse gas discharges.
- It decreases the hazard of water contamination.
- It can decrease the country's dependency upon imported energy sources by producing energy from domestic supplies.
- Waste administration, including the aid of advanced pyrolysis technology, is economical than removal to landfills.
- The development of a pyrolysis energy plant is a comparatively fast method.
- It produces numerous different businesses for low-income people depending upon the amounts of waste produced within the area, giving public health advantages by garbage clear out.

5.6. Gasification

In this method, to provide gas and char in the first step and succeeding conversion brought out the incomplete oxidization of biomass of output gases, mainly CO_2 and H_2O, with the charcoal within CO and

H_2. Reliant upon the reactor's configuration and working positions, the operation also produces CH_4 and other more essential hydrocarbons (HCs) [125]. Generally, gasification may be described as the thermochemical transformation of a solid or liquid carbon-based substance (raw material) [126,127] within a flammable, volatile commodity with the stocks of a gasification factor (different gaseous aggregate). The gasification agent facilitates the raw material to be immediately transformed within gas using diverse heterogeneous reactions. If the operation does not happen with an oxidizing agent's aid, indirect gasification requires an outer energy reservoir gasification agent because it is simply manufactured and improves the combustible gas's H_2 content [128, 129].

Table 2 compiles the merits and demerits concerning the kinds of the reactor Reprinted with permission from Ref. [130].

5.7. Physico-chemical techniques for polymer recycling

PPE waste recycling approaches vary among nations, but these practices depend upon few simple essential ingredients. Scrap plastic is gathered from residences, hospitals, institutions and other collecting locations and carried to garbage administration equipment, classified within various polymer classes [131]. It supports ensuring that all scrap stream allows a comparatively clean cause of one appropriate polymer particle, composing them fit for reprocessing new stocks. During the processing equipment, plastic is stripped, and some contaminants are eliminated. While mechanical recycling methods, the synthetic is melted and ejected to be re-formed within novel plastic goods, such as containers, clothes threads, carpeting's, and furniture. However, the characteristics of plastics generated by mechanical recycling are usually inferior to those generated from natural raw materials. This form of recycling is seldom named 'downcycling' because its outcomes have a lower cost than the new plastics [132]. The recycling of plastic is not as tricky as constructing fresh plastic commodities. It requires definite methods and consideration to aspect. The methods sometimes longer time as usual. Irrespective of the kind of plastic and its practice, it usually encounters some typical levels while recycling. Here are six primary trails to recycle plastic supplies are given below:

5.7.1. Acquisition of waste plastic

The initial step to plastic recycling is collecting waste plastic commodities as this method may look like a simple job but not so easy [133].

At this step, workers or volunteers work around getting scrap plastic from residences, offices, and ordinary places. Some areas have group localities where people may place their plastics. Few recyclers put recycling bins in public areas, household fields, and manufacturing zones to facilitate the acquisition. People can discard their plastic garbage within these bins. The recycle bins then get accumulated and carried to recyclers to sustain the method.

5.7.2. Ordering of plastics within classes

After recovering, recyclers send the plastic they have collected to plants to assign the plastics as per its class. As it is well known, PPE waste varies in dimension, color and application. In this method, recycling devices classify plastics based on the characteristics of the substance [134]. Usually, the color and the resin content within the plastic are the base by that recycler's kind of plastics. Sorting is crucial because it enables recyclers to identify what kind of material is included and how it becomes recovered.

5.7.3. Cleaning to eliminate contaminants

After classifying plastics, recyclers clean the materials to eliminate contaminants. These contaminants into plastic hold paper stickers, dust, and bits. Wash plastic also eliminates adhesive and supplementary substances, which plastic substances may include [135]. Cleaning is crucial because failure to eliminate contaminants can harm the novel product. Furthermore, the contaminants included in plastic commodities are not synthetic substances and may not be recyclable.

5.7.4. Shredding and Resizing

This method appears quickly after cleaning plastics. This is not easy to reuse synthetic within its already advanced state. There is a requirement to resize the plastic substance toward a form that may be recovered. In this method, substances will be placed into shredders to decrease the plastic within pieces. A plastic matter split within small parts is more suitable to prepare than in its innovative form. Shredding also makes it feasible to reprocess plastic to other substances away from plastic commodities. Resizing also makes it simpler to know elements like metal that recyclers failed to find during cleaning.

5.7.5. Identification and the parting of plastics waste

After resizing has been achieved, the following method is to know and classify plastic substances. During this method, plastic bits undergo testing processes. The purpose of testing plastics is to know the type and character of the plastic. The plastic substances are then classified depending upon their characteristics for additional processing. There are numerous points examined during this process. One of these conditions is density. Recyclers put these plastic bits within a vessel of water to define the density of plastic. The bits that settle are less compact, while those that swim are more impenetrable. This process also recognizes other features like the color and melting point of plastic—recyclers test specimens of plastic substances to define each material's melting point and color. Following the classification method, they separate the plastic bits and send them for additional processing.

5.7.6. Compounding

Compounding is the last method of plastic recycling. This step is where recyclers change plastic particles into substances that manufacturers can regenerate. Compounding includes crushing and melting plastic bits to produce grains. This method is also named extrusion. Sometimes, recyclers transfer plastic to several areas where it may be recovered. The recyclers may transfer the substances to other plants because of the characteristics in step five. A recycling corporation cannot have the ability to prepare all the plastic sorts it recognizes.

After this step, new plastic and non-plastic commodities arise from the pellets' processing. This last method also spends the maximum time and energy. Recyclers must thoroughly know the finished outcome they intend to take and the complete method to handle time and energy efficiently. Plastics assist many objects in our everyday life. This article has demonstrated PPE waste recycling and the advantages the world persists in achieving if we recycle synthetic. So, when next you empty a plastic bottle, do not just throw it off. Be assured to dispose of plastic in a form that makes it desirable for it to become recycled.

6. Chemical and apparatus used in the recycling process

6.1. Chemical treatment

The disaster-induced through the COVID-19 epidemic has changed worldwide waste production dynamics and has gained significant consideration. The instantaneous variations within waste production and amount also need a progressive push from policymakers [136]. Chemical reprocessing, also named as exceptional plastic recycling, is one such example in detail. Chemical recycling intends to completely recycle plastic goods by converting them to their original feedstock state to repurpose manufacturing goods like oils and waxes or convert them into pure plastics. The chemical processing of COVID-19 waste can be categorized within chlorine- and nonchlorine-dependent operations. The antiseptic solution utilized as NaOCl or ClO_2 in a chlorine-based processing method, where the electronegativity of chlorine assists during oxidizing peptide bonds and denaturing proteins, supports the diffusion of cell sheets at neutral pH [137]. NaOCl is one of the first chemical sanitisers that delivers halo acetic acid, dioxins, and chlorinated aromatic composites. The application of ClO_2 developed, which is a potent biocide; though, this is practiced on-site owing to its uncertain nature. Furthermore, it decays to produce salt and less toxic results, which are nonreactive to alcohol/ammonia. On the other side, H_2O_2 is generally utilized as the disinfectant tool in a nonchlorine-based processing method [138]. This works to oxidize and denature proteins and lipids, creating the membrane's disorganization by expanding the saturated H^+ ions. High reactiveness and no poisonousness compared to the chlorinated system is beneficial to practice this method [139]. Various kinds of scrap plastic were assembled, washed and chopped in small portions during the liquefaction method. PS, PVC, PE, PP and PETE scrap plastics, including activated carbon, were set within the reactor container toward the liquefaction operation [140,141]. The catalyst was used zinc oxide (ZnO) and aluminium oxide (Al_2O_3) as 1% toward the liquefaction operation. Activated carbon, ZnO and Al_2O_3 was received, and all were in powder form. The reactor employed is the method is stainless steel reactor. The ZnO is a light catalyst, and were not decreased the liquid yields. This did not influence the water-insoluble portion (lignin-acquired), but it crumbled the diethyl ether-unsolvable section. Few signs of catalyst inactivation were also perceived. The oil units were developed thermally and the change of thickness and invented water content. The viscosity's progress was suggestively lower during the ZnO-operated oil (55%) than for the reference oil in the absence of any composite (129%) [142]. Alkali-treated Al_2O_3 composite (1%, 3%, 4%, and 5% with mass of employed specimen) was practiced during the pyrolysis operations. Attention has been concentrated upon gasoline-enrich engine fuel generation. The maximum gasoline yields were 53.8% towards the gasoline by sunflower oil that may be recovered from the pyrolysis, including 5% catalytic tracks [143]. Regrettably, chemical recycling is yet trying to flourish besides the efficiency and economics of fossil fuels. It has produced various chemical recycling plants to abandon.

6.2. Apparatus

Stainless steel apparatus is the container by the vessel construction layout and parameter shape to complete the heating, distillation, cooling, and low-speed mixing function demands. The reactor is generally utilized within the petroleum, chemical, rubber, medication, food, and pressure container to make vulcanization, hydrogenation, polymerization, and decomposition containers. The polymerization reactor is usually made of carbon and manganese steel, stainless steel alloys, and other composite substances [144,145]. The batch reactor, commonly a stainless-steel apparatus, is a known name extensively utilized by manufacturers. Its title is something of a misnomer since containers of that kind are practiced toward various method processes, for example, solids dissolution, stock mixture, chemical reactions, pyrolysis, etc. The stainless-steel reactor comprises an agitator and an integral heating/cooling arrangement within a volume from 1 to 15,000 lit [146]. Fluids and solids are normally charged through joints at the head covering of the reactor. Connections at the top and liquids also release vapours, and gases are generally discharged outside the ground.

6.2.1. Principle

The power unit drives in the fixed direction through the agitator rotation of the reactor. Throughout the process, it makes substances rotate vertically or horizontally. Elements inside the reactor are under both axial and circular movement, producing various mixing forms, for example, shearing, processing and dispersion stirring. Therefore, the elements may be efficiently quickly mixed and processed. Boiling or cooling fluids will be drawn in the reactor jacket as the warming or cooling reservoir. The goal of heating and cooling is to give the generator proper warmth to fulfil the reacting condition. Besides, cooling is practiced for reducing the heat to pack finessed substances. The reacting forms sometimes require the correct pressure to match the necessities and inert gas toward stability.

6.2.2. Working

The reactor container consists of a mixing pot pushing the motor and an agitator. The reactor driving with machine and agitator within is among processing function. It continues running correctly, and materials inside will be mixed and reacting with other extracts [147]. Meanwhile, the temperature is raised by the reacting procedure. So, the cooling jacket is employed at the same time to switch the weather. An agitator is a tool utilized to introduce a motion to stir toward the liquids or semi-solids. The cooling fluid flows via the jacket, accumulating heat power from the reactor vessel's outer surface and giving it off as the cooling fluid outlets on the jacket exit. While the stream of cooling fluid by the jacket rises, more heat is extracted. Within a chemical vessel, baffles are usually fastened to the inner surfaces to improve blending and enhance heat transference and probably chemical reaction movements.

7. Conversion of PPE kits into a liquid biofuel

Gas chromatography and mass spectroscopy (GC-MS) study of PETE, PE, PVC, PP and PS blend to fuel subsequent classes of the composite have been identified upon retention time (t) and trace mass (m/z). The fuels generated are recognized as biofuels, these fuels are beneficial and are practiced rather than extinguishable fuels such as petroleum, diesel, etc.

7.1. Bio-fuels

Biofuels are of renewable energy origins formed from organic material or scrap, contributing to decreasing carbon dioxide (CO_2) discharges. Biofuels are one of the most prominent roots of renewable energy in practice now. Within the transport division, they are mixed beside subsisting fuels like gasoline and diesel [148]. This may be especially valuable soon to help decarbonize the aviation, marine and heavy-duty highway transportation areas. Biofuels may be generated by organic material or biomass, like corn or sugar, vegetable oils or scrap materials [149]. As biofuels release a smaller amount of CO_2 than standard fuels, they can blend, including subsisting fuels, to decrease CO_2 emissions within the transport area. The application of biofuels has increased across the past years, mainly driven by introducing new energy systems in Europe, the USA and Brazil, which ask for higher renewable, less-carbon fuels towards transportation. Now, biofuels draw about 3% of highway transportation fuels into usage throughout the globe.

7.2. Types of biofuels

At present, most of the biofuels are originated from crops and are termed conventional biofuels. Innovative types of machinery and methods that generate fuels through scrap, contaminated harvests or forestry outcomes are being produced, and these fuels are recognized as excellent or second-generation biofuels. Exceptional biofuels are expected to grow the original mode of biofuels during the prospect to develop their sustainability [150,151]. Like different renewable energy roots, biomass can be converted straight into fluid fuels, named "biofuels," to match transport fuel requirements. A couple of the most popular kinds of biofuels into use now are ethanol and biodiesel, both of which describe the first generation of biofuel technology [152].

7.2.1. Ethanol

Ethanol, typically a biomass-based renewable fuel (recognized as bio-ethanol), is produced through the alcoholic agitation of animal and/or agricultural residuals [153,154]. Ethanol is generally classified into two classes: hydrous and anhydrous ethanol. Hydrous ethanol is wet ethanol, which is typically generated through the distillation of organic biomass, and that is 95% ethanol and 5% precipitation content. Hydrous ethanol is being used as fuel in combination with 15% petroleum fuel.

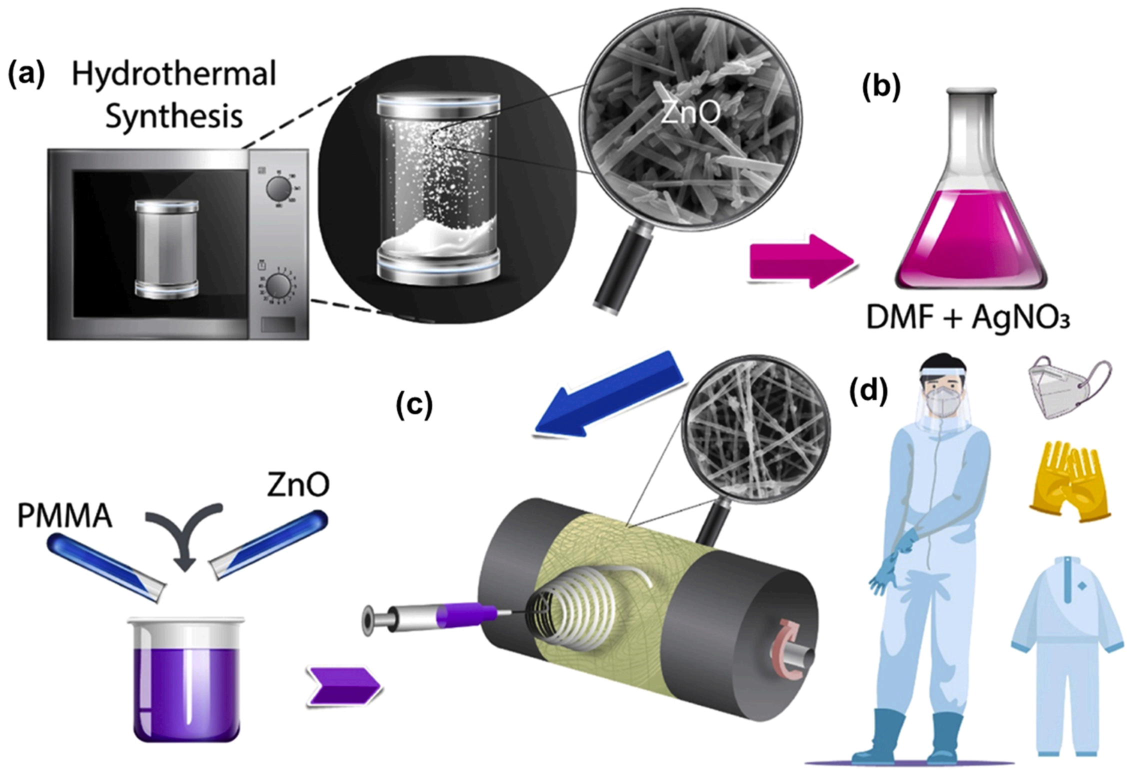

Fig. 11. (a-d) The synthesis process and schematic representation of shielding apparel comprise PMMA/ZnO-Ag NFs. Reprinted with permission from Ref. [164].

On the opposite side, the anhydrous ethanol is produced through dehydrating the wet ethanol (hydrous one). The ethanol content within the anhydrous nature is 100%, which may be utilized as a fuel individually [155]. In both of its kinds, ethanol is a transparent liquid fuel including a characteristic odour and a chemical formula (C_2H_5OH). This is a lead-free fuel having a volatile structure content; therefore, it should not be exposed to air in storage conditions. Ethanol comprises oxygen within its chemical construction, and it is more valuable than benzene and diesel fuels in fire motors, particularly during high altitude nations/towns where the atmospheric oxygen level is low. This has a tremendous self-ignition heat compared to gasoline and diesel fuels [156]. This is also a nontoxic fuel and safe during drinking and breath circumstances. It mixes with air during combustion, providing water; therefore, it should be stored far from precipitation into storage conditions to avoid decreasing the fuel concentration, e.g., lowering fuel capability. Occasionally ethanol is combined with lead-free gasoline/diesel to enhance fuel characteristics, for example, octane/cetane number, fuel production, oxygen content, etc. [157]. Oxygen-fueled ethanol has a natural impact on pollutant discharges. It has been observed that wet ethanol has a lower octane number among various ethanol than the dry one. The higher the octane number, the higher the fire chamber's condensation ratio and the motor propulsion. Ethanol could also be utilized solely as a fuel (primarily anhydrous nature), and it could be combined with gasoline (toward both kinds) at any rate [158]. Ethanol also works as a blending tool with gasoline to boost octane and lower carbon monoxide and other smog-causing discharges. The most popular blend of ethanol is E10 (10% ethanol, 90% gasoline). Few transportations, described as flexible fuel vehicles, are intended to operate at E85 (a gasoline-ethanol blend comprising 51–83% ethanol, depending upon geography and season) as alternative fuel including much higher ethanol content than conventional gasoline. Roughly 97% of gasoline within the United States includes some ethanol [159]. It is utilized in blended fuels, including petrol, either on low levels in conventional vehicles (capable of 10%) or on higher levels within cars modified to get petrol and ethanol, recognized as "flex-fuel" vehicles.

7.2.2. *Biodiesel*

Speedy energy loss and human dependence upon fossil fuels have resulted in the accumulation of greenhouse gases and, consequently, influence environmental change. As such, significant attempts have been made to improve, experiment, and use clean, renewable fuel options. The generation of bioethanol and biodiesel by crops is fully grown. Simultaneously, other supplied resources and methods have also conferred high potential to produce effective and economical substitutes, for example, landfill and plastic garbage regeneration, algal photosynthesis, and electrochemical carbon fixation [160]. Biodiesel is a diesel fuel obtained by plants or animals and consists of long-chain fatty acid esters. It is typically composed of chemically reacting lipids, such as animal fat, soybean oil, or other vegetable oil, including alcohol, methyl, ethyl, or propyl ester [161]. Therefore, recycling the plastic waste generated during this pandemic is necessary by following proper strategies and methods [42].

8. Biorenewable materials in PPE kits for textile components

Biorenewable substances can usually be estimated within three groups. Nanocomposites contain renewable additives, nanocomposites containing biorenewable source patterns, and nanocomposites with additive and matrix structures depend upon biorenewable sources [162-165,175]. Cellulose, starch, chitosan, pectin, hyaluronic acid, lignin, and natural rubber are few like biorenewable substances [166–173]. It is usually applied as a pattern because of its comfort of accessibility, economic benefits, biodegradability, and processing efficiency. These are practised to enhance biocompatibility in pharmaceutical purposes and strengthen the adherence of adequate materials to the composite composition [162]. In the present scenario, the need for eco-friendly antimicrobial materials and textiles is increasing. To decrease pollution generated with non-degradable synthetics, an antimicrobial cellulose fabric comprising Ag nanoparticles was made in a study. Cellulose fabrics are utilized in various enterprises [174], such as pharmaceutical textiles, and are extensively employed to prepare PPE during the COVID-19 pandemic [163]. In the recent investigation, fabric-based nanocomposites were synthesized through ultrasonic waves within a facile, green, and single-step method. Cellulose mechanoradicals were formed through ultrasonication of cotton suspension and wreckage of 1,4-glycosidic bonds. Next, with formed mechanoradicals, the metal ions (Au^{3+} and Ag^{+} ions) within the suspension were decreased to metal nanoparticles. Lastly, metal nanoparticles were incorporated into the fabric. [163].

Karagoz et al. [164] developed antimicrobial, antiviral, and self-healing nanofibers by the incorporation of poly(methyl methacrylate) (PMMA), including ZnO nanorods and nano-Ag. Multifunctional coverings to alteration of protecting clothes were composed (Fig. 11 **a-d**). For this purpose, initially, ZnO was formed through a hydrothermal method, and Ag was made through the reduction of $AgNO_3$. A suspension comprising a polymer, ZnO, Ag nanoparticles were developed, and later this suspension was electrospun at a cover and put on the interior surface of the framework.

The antibacterial textile was made toward restricting scar disease within the clinic. In this regard, polydopamine and polyethyleneimine were placed upon the cotton substance. They cross-linked gallic acid/Ag nanoparticles (GA/Ag-NPs) by H- bonding. The incorporated material displayed an anionic exterior because of GA/Ag-NPs. This low-cytotoxicity altered textile was repellent to bacteria due to electrostatic repellence. Furthermore, delivering Ag^{+}, it had solid antimicrobial activity [165].

9. Conclusion and future prospects

Currently, the world focuses on combating COVID-19; though, we can anticipate the concerns regarding economic disaster and ecological asymmetry. We have to progress individually to match the hurdles generated with the COVID-19 pandemic to manage sustainability. There is extensive use of PPE to reduce/eliminate the risk of COVID-19 infections. We have discussed some critical issues and recommended efficient recycling of PPE kits (used and faulty) using different technologies. This growth will block the critical after-effects to humankind and the atmosphere and provide a reservoir of energy. Therefore, to produce the value-added product from PPE kits waste, the waste administration's challenges and the growing energy market have been addressed simultaneously. The liquid fuel manufactured from plastics is clear and have fuel characteristics comparable to fossil fuels. For addressing the plastic contamination issues, the subsequent suggestions have been made: (i) The destruction of contaminated PPEs should be meticulously managed through qualified waste accumulators and properly bagged, abandoned or reused to stop disease and related health hazards, environmental contamination, and injuries to marine animals and other marine wildlife. (ii) Due to plastics' rising consumption worldwide, an excess of SUPs would probably end up as mismanaged plastic garbage. Hence, importance should be put upon the intended decrease in abandoned plastic garbage. This would drastically decrease the millions of PPEs that would have been scattered in the sewers, thus limiting the blockage of waterways, flooding of urban cities, and supporting the decrease in transmission of dangerous viruses.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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