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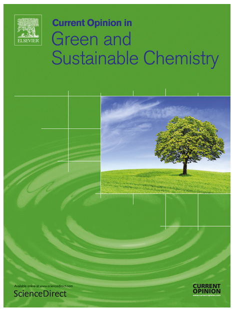

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Recent developments in recycling of polystyrene based plastics

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Abstract

Due to their superior properties, plastics derived from petroleum have been extensively used almost in everyday life since last few decades. Because of lack in the manageability of plastic solid waste, their volume is increasing steadily in the natural world. Unfortunately, the disposal of plastics wastes in the oceans and land filling has led to a global issue. To effectively and efficiently deal with plastic solid waste is becoming a great challenge for the society as plastic solid waste creates big threat to our environment. Recycling of plastics solid waste should be performed to produce products having same quality to original plastics. This review article gives an overview of plastics solid waste with particular emphasis on the recent progress in polystyrene based plastics.

Keywords: Plastic solid waste; land filling; recycling; polystyrene; polystyrene based plastics

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Introduction

The 20th Century has got topping achievements in petroleum-based plastics and plastic has gained important role in human life as well. The use of plastic in everyday life is growing with significant rate [1] i.e. 1.65 to 311 million tons worldwide [2] from 1950 to 2014 respectively. Due to various promising characteristics such as low density, durability, low cost and easily moldable, plastics have found useful applications in human life including electronics, packaging materials, farming, automobile and building construction to name a few [3]. According to one of report, worldwide output of 322 million tons for plastics has achieved in 2015 [3]. In Europe, plastics of 39.9%, 19.7% and 8.9% are due to packaging, building construction and automotive respectively. Above 80% of plastics in Europe are composed from polystyrene, polyethylene, polyurethane, polyvinyl chloride, polypropylene, polyethylene terephthalate and fossil-based plastics [3,4]. This review briefly sums up the issues regarding the plastics solid waste. The polystyrene based plastics have been reviewed in detail in this article.

Plastic solid waste: global issue

As many products of plastics are being utilized with the growth of world, plastic solid waste is becoming a global issue [5]. Hazardous effects are created on the environment due to nonbiodegradable nature of plastic. This results landfilling of plastic waste and leads to the hard environmental issues [6]. Pigment of plastic waste comprises of numerous toxic elements[7].The groundwater has been contaminated from the release of toxic chemicals in plastic waste [8]. Plastics solid wastes to landfills can enter the environments of marine, approximately 12 million tons of plastics waste was found to move into the seas in 2010 [9]. Marine mammals are being tangled in plastic detritus and are adversely affected by plastics contamination [10–12].

The presentation on the treatment of plastics waste was given by European Union in 2012 [13,14]. Out of entire plastics wastes, percentages of 26, 0.3 and 35.6 were reported for mechanically recycled, feedstock recycling and energy generation respectively in 2012, disposal percentage was 38.1. As polymers have prominent energy value, plastic wastes were used as fuel by incineration. The average value of energy generation rate for 29 countries was 36% in which 19 countries had less value than average value [14]. Energy generation by recycling of plastics wastes is at the moment one of the most eco-efficient method because of bulk process, follow almost every strict emission rules and energy requirement [15,16]. However, many hazardous chemicals such as gases and dioxins can be evolved from the incomplete combustion of solid wastes, leading to severe environment pollution. Hence, combustion of solid wastes should be according to environmental standards defined by European Union [14,17].

Table 1 shows the characters and amounts of plastic used by USA in 2012 [14,18]. A quantity of 31.7 million tons of plastics was produced and 12.7% was accounted for plastics wastes in municipal solid wastes in 2012, out of 12.7%, 8.8% of plastic waste was recycled and rest was disposed. Recycling rate of 20% and 15% were reported for polyethylene terephthalate (resins) and polyethylene respectively but negligible amount of solid wastes composed of polyvinyl chloride, poly lactic acid, polypropylene and polystyrene were recycled [14]. It was found that approximate 80 times more production of plastic solid wastes in 2012 as compared to in 1960 [18] and till 1980, there was 0 % recycling of plastic waste. Hence, recycle rate of plastic waste enhanced to just 8.8% for time period of 30 years i.e. from 1980 to 2012.

Table 1. Plastics used by USA [14,18]

Plastic polymers	Generation	Recovery		Discards
	(1000t)	(1000t)	Rate (%)	(1000t)
Poly-ethylene terephthalate	4520	880	19.5	3640
High-density polyethylene	5530	570	10.3	4960
Polyvinyl chloride	870	Neg.	Neg.	870
Low-density polyethylene/linear lowdensity polyethylene	7350	390	5.3	6960
Poly lactic acid	50	Neg.	Neg.	50
Polypropylene	7190	40	0.6	7150
Polystyrene	2240	20	0.9	2220
Other resins	4000	900	22.5	3100
Total plastic in municipal solid waste	31,750	2800	8.8	28,950

Recycling of plastic solid waste

Recycling of plastic wastes to construction industry is regarded as one of the best disposal method for plastics solid wastes **(Figure 1)**. Plastics wastes can be handled by using following methods [19]: (a) land-filling, (b) incineration, (c) chemical recycling and (d) mechanical recycling. Land filling requires lots of space and pollutes the environment. Land filling of plastic wastes is not preferable and the European Commission has set the goal for zero land filling by 2025 [16]. No waste is left and high calorific values of plastic waste polymer are the advantages of incineration, however carbon dioxide, toxic chemicals, harmful ash are formed. Mechanical recycling is also known as physical recycling. Mechanical recycling is used to reuse the plastic solid waste to form the product with same inherent characteristics [16,20] whereas in chemical recycling, plastic waste is converted into fuels and chemical feedstocks by using various treatment such as pyrolysis and hydrothermal [21,22]. By using chemical recycling, polyolefin's can be converted into oil/hydrocarbon, polyesters and polyamides can be turned back into respective monomers [23].

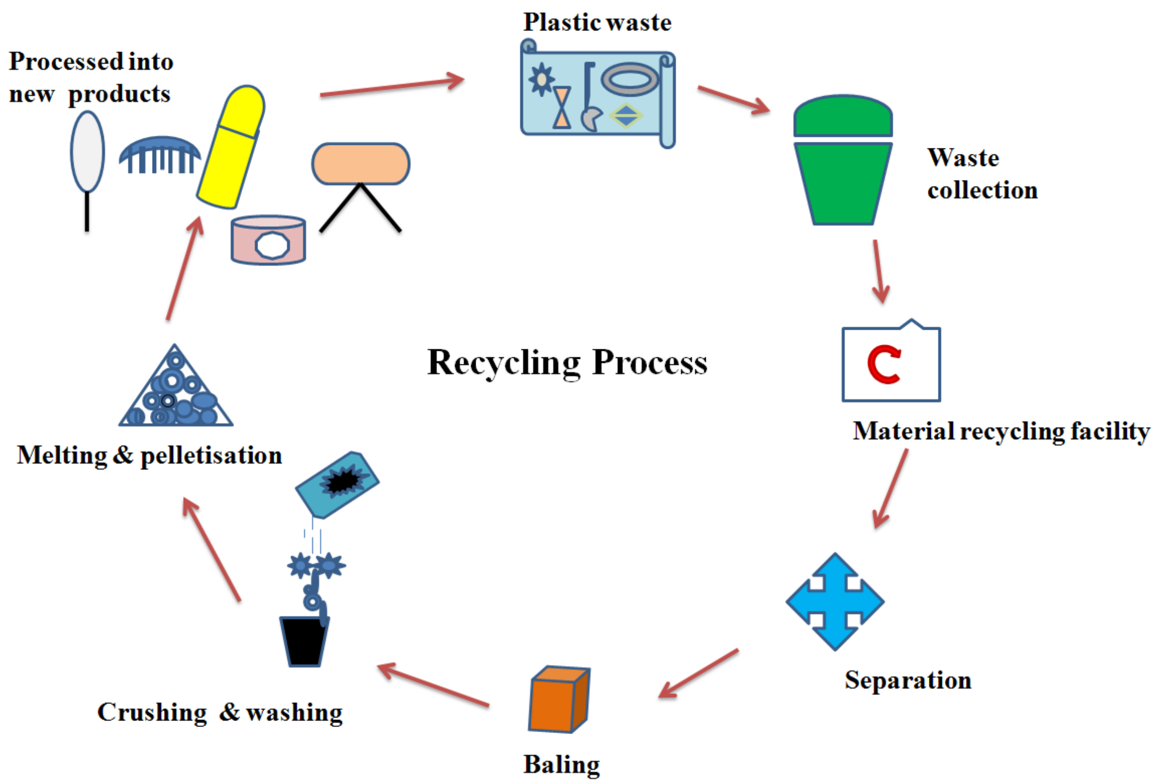

Figure 1. Schematic representation for recycling of plastic solid waste.

Polystyrene based plastics

Recently, polystyrene based plastics have been used in various applications [24–81]. Polystyrene-based plastic wastes of electrical and electronic equipment consist of acrylonitrilebutadiene styrene and high impact polystyrene [82]. Mainly 30-50% of plastic waste is because of the electrical field and electronic equipments [83]. Truc and Lee reported the separation of plastic waste of acrylonitrile-butadiene-styrene as well as high impact polystyrene by using froth floating technique after the coating of zinc oxide and microwave treatment [36] **(Figure 2)**.

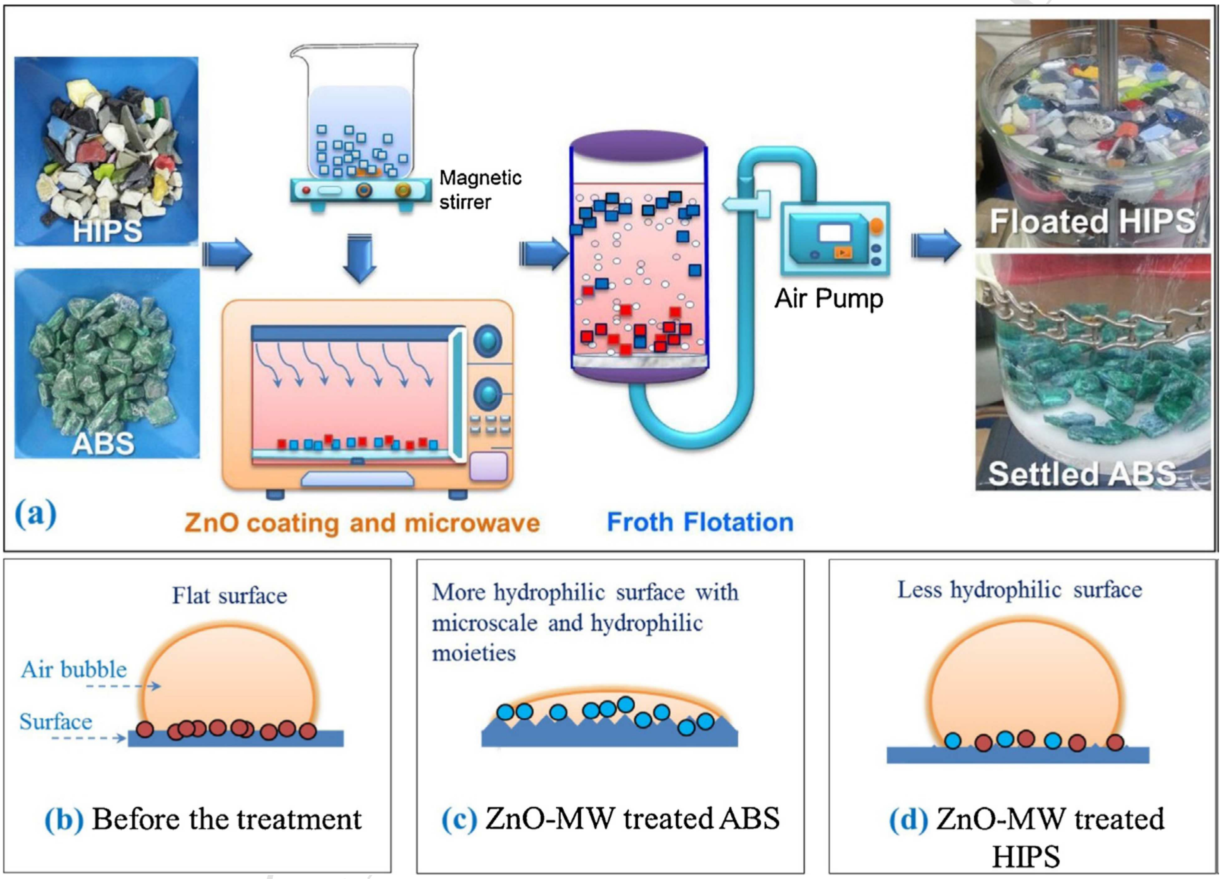

Figure 2. (a) Froth flotation and ZnO coating-microwave (MW) treatment for the separation of plastics mixture of acrylonitrile-butadiene-styrene (ABS) and high impact polystyrene (HIPS), (b,c,d) presentation of surface changes in acrylonitrile-butadiene-styrene (ABS) and high impact polystyrene (HIPS) before and after ZnO coating-microwave (ZnO-MW) treatment [36]. Reprinted with permission [36]. Copyright 2017 Springer.

The hydrophilicity of acrylonitrile-butadiene-styrene on coating of zinc oxide and microwave treatment was more enhanced as compared to treated high impact polystyrene **(Figure 2b,c,d)** which resulted in the sank down of acrylonitrile-butadiene-styrene in the flotation cell [84]. The treated high impact polystyrene floated over the solution **(Figure 2a)** and after 2, 3, 4 and 5 minutes, the floating recoveries were 100 %, 95.2 %, 80.4 %, and 81 % respectively. Thus, after 2 minutes, zinc oxide coated acrylonitrile-butadiene-styrene (100% sinking) and high impact polystyrene (100% floating) became completely separated from the plastic mixture **(Figure 2a)**. In another work, froth flotation method was used to separate the toxic poly(vinyl chloride) from mixture of plastic wastes including polystyrene [35] **(Figure 3)**. The surface of plastics was treated with calcium hypochlorite for separation process. Poly(vinyl chloride) was effectively distinguished from mixture of plastics wastes with 0.37 % residue **(Figure 3)**. Another plastics, mainly poly(acrylonitrile-co-butadiene-co-styrene) (8.04%) and poly(methyl methacrylate) (8.37%) were also collected with purified poly(vinyl chloride). The polarity and surface roughness of poly(vinyl chloride) were increased by treating with calcium hypochlorite, that led to enhanced surface wettability [85]. The different molecular structure of plastics was responsible for the different floating characteristics of plastics. Wang and Wang developed an environment-friendly froth flotation technique with Fenton treatment for the separation of polyvinyl chloride from plastic mixture consisting of polystyrene and polycarbonate [33]. On Fenton treatment, the floating capability of polystyrene and polycarbonate was decreased selectively but it remained unaffected in case of polyvinyl chloride. The wettability of substance was evaluated by measuring contact angle. The contact angle for polyvinyl chloride showed very small change after Fenton treatment but it was decreased for polystyrene and polycarbonate from 92.87° to 76.32° and 91.14° to 78.87° respectively. The surface wettability was increased because of reduction in contact angle [86]. According to FT-IR and XPS analysis, due to the introduction of polar groups on Fenton treatment, hydrophilicity of polystyrene and polycarbonate was increased [87]. The surface roughness of treated polystyrene and polycarbonate was enhanced as confirmed by SEM morphology. The reported purity and recovery of separated polyvinyl chloride were 99.26 % and 100 % respectively.

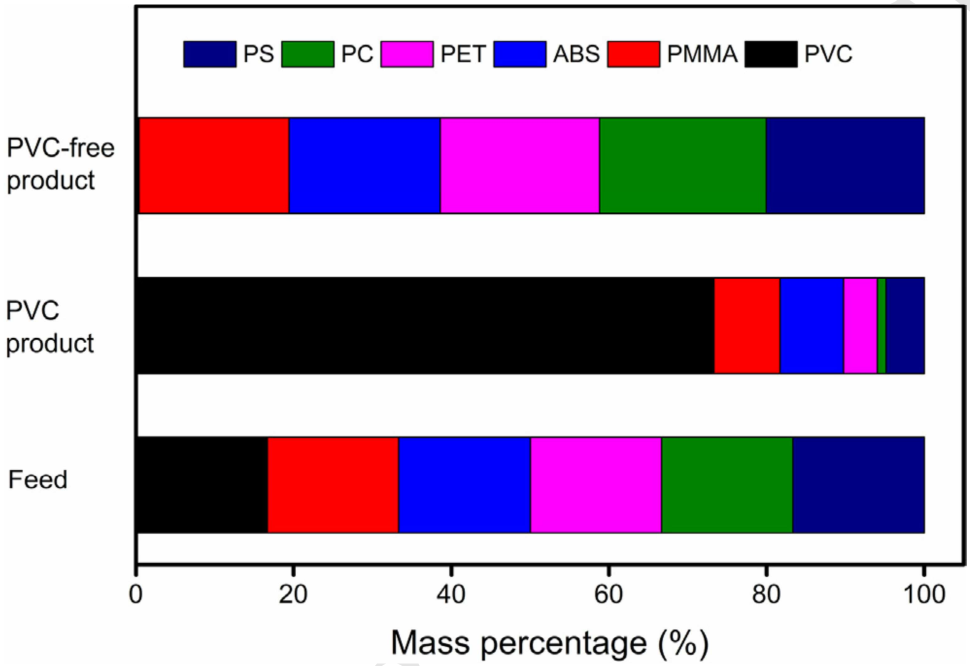

Figure 3. Separation of plastic mixture [35]. PS: polystyrene, PC: polycarbonate, PET: poly(ethylene terephthalate), ABS: poly(acrylonitrile-co-butadiene-co-styrene), PMMA: poly(methyl methacrylate), PVC: poly(vinyl chloride). Reprinted with permission [35]. Copyright 2017 Springer.

Marta Vila-Cortavitarte and co-workers explored the various benefits that came through the substitution of bitumen with polystyrene in the asphalt mixture [26]. They have used three different types of recycled polystyrene wastes: general purpose polystyrene, high impact polystyrene and polystyrene from hangers as additives in the concrete mixture. The core motive of this work was to reduce the concentration of bitumen in asphalt mixtures since emissions of carbon from bitumen can pollute the environment. The replacement rates of 1% and 2% by polystyrene in asphalt mixture corresponded to the 23% and 46% of total bitumen. The mixture with 2 % was discarded because of cohesion problem. Every sample was passed through a set of tests to compare the modified mechanical properties. A mixture having 1 % of replaced bitumen by polystyrene showed the higher number of voids with improved mechanical properties. The results showed that replacement of bitumen by polystyrene reduced the environmental issue, contributed to the life cycle assessment [88].

The proper development of the catalyst leads to obtain desirable products with low cost [89]. Tertiary recycling is being used to get most profit of plastic wastes, hydrocarbons are being produced [90]. Metal as catalyst for decline of polystyrene was decorated with montmorillonite [31]. Polystyrene solid waste was converted into ethylbenzene, toluene, α-methylstyrene and styrene by using 5 % Al/ montmorillonite and 20 % Fe/montmorillonite as catalyst [31].The amount of 8.49 % (wt./wt.), 5.13 % (wt./wt.), 49.28 % (wt./wt.) and 2.80 % (wt./wt.) was reported for toluene, ethylbenzene, styrene and α-methylstyrene respectively utilizing 5% Al/ montmorillonite and 10.15 % (wt./wt.), 6.42 % (wt./wt.), 50.93 % (wt./wt.) and 2.31 % (wt./wt.) respectively utilizing 20% Fe/montmorillonite. Tuffi et al. investigated the thermal degradation for mixed plastics wastes of polystyrene, polypropylene, polyethylene film and poly(ethylene terephthalate) [25]. The Kissinger-Akahira-Sunose technique was used to perform the kinetic study. The activation energy for pyrolytic of polystyrene, poly(ethylene terephthalate), polypropylene and polyethylene was found in the range of $0.25<\alpha<0.85$. Thermal degradation of mixture with more polypropylene was performed through single step. The temperature, composition and structure were the factors that influenced the thermal behavior of mixed plastics waste. The risk of fire can be reduced by introducing flame retardants into inflammable materials [91]. Plastic samples can be evaluated for their flame retardants content in regard to reduce the risk from fire [92]. In one of work, amount of 26,000,000 ng bromophenols (tetrabromobisphenol A)/g was reported in acrylonitrile butadiene styrene whereas it was 330,000 ng ∑hexabromocyclododecane stereoisomers/g for polystyrene [34].

Outline

For a greener environment as well as to reduce the plastic waste disposal, petroleum based materials need to be replaced with biodegradable, recyclable and renewable polymers. Recycling of plastics wastes will minimize the global warming and enhance the sustainability. Recycling of plastics is the need of closed loop cycle that should meet the rules of circular economy. Mechanical recycling is the shortest track to reuse the plastics waste. From economy point of view, chemical recycling is not suitable for petroleum based plastics because petrochemical feedstocks are cheaper as compared to process. Biological recycling produces mainly carbon dioxide and water as final products that can be used in life cycle through photosynthesis. Thus biological recycling is the longest track and can only be applied if mechanical cycling and chemical cycling are not usable.

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* * of outstanding interest

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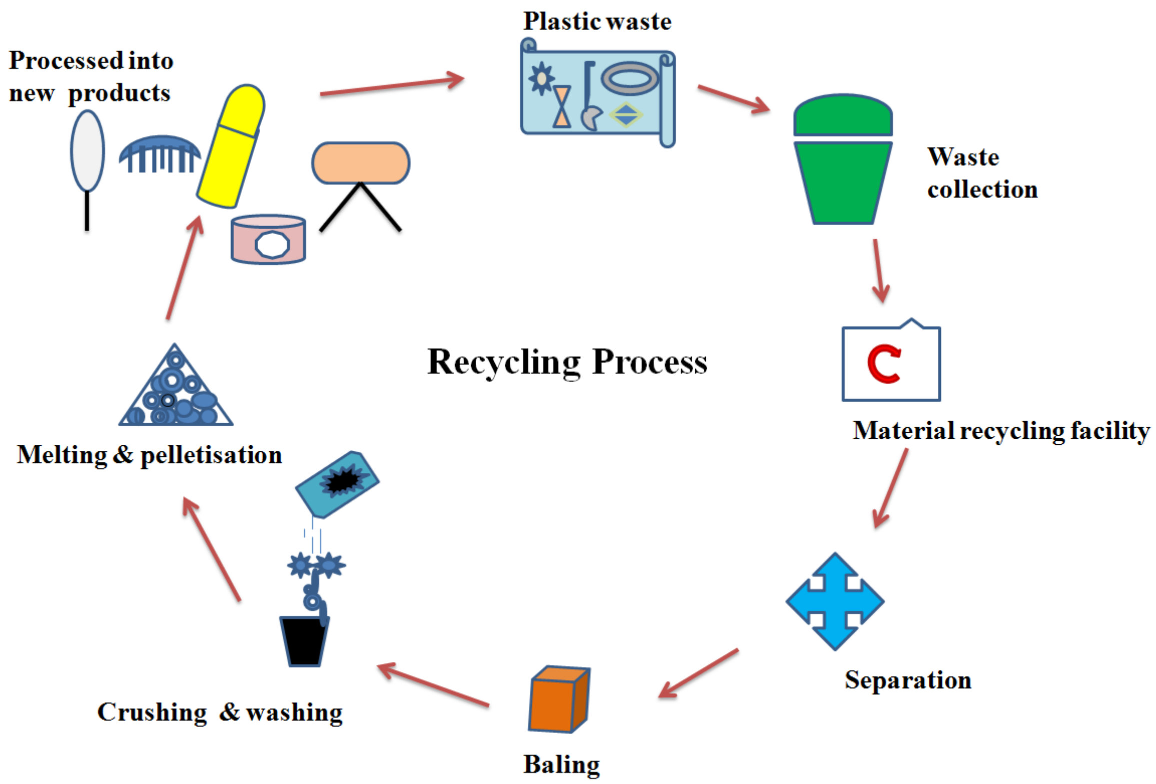
Highlights

- Plastic solid waste is a burning global issue.
- Recycling of plastic solid waste is useful from economic and environmental points of view
- Polystyrene based plastics are useful in numerous applications.

Graphical Abstract



Recent developments in recycling of polystyrene based plastics

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