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An Analysis upon Recycling and Disposal Scenario of Electronic Waste: A Case Study of Indian Context

Kolla Pushpa Nandini

Research Scholar, Mahirishi University, Lucknow

Abstract – However, India is rich in ores and mineral, but E-waste recycling is necessary due to the report of national and international studies, which cautioned on the generation, treatment and accumulation of e-waste in India. Current data indicate that the total domestic e-waste generation including imports is around 382979 MT, however waste available for recycling and actually recycled are 144143 MT and 19000 MT, respectively. In which recycling by non-formal and formal sector are 95% and 5%, respectively. On the other hand, India has developed expertise in handling verities of metallic wastes in an organized and safe manner. The development of individual process or combined processes for handling the e-waste is underway. Eco- friendly and energy-saving processes are necessary to comply with stringent environmental regulations.

The paper includes the recent trend of e-waste generation, recycling process and its future prospects particularly in India. Informal recycling is a new and expanding low cost recycling practice in managing Waste Electrical and Electronic Equipment (WEEE or e-waste). It occurs in many developing countries, including India, where current gaps in environmental management, high demand for second-hand electronic appliances and the norm of selling e-waste to individual collectors encourage the growth of a strong informal recycling sector.

New formal e-waste recycling systems should take existing informal sectors into account, and more policies need to be made to improve recycling rates, working conditions and the efficiency of involved informal players. A key issue for India's e-waste management is how to set up incentives for informal recyclers so as to reduce improper recycling activities and to divert more e-waste flow into the formal recycling sector.

E-waste contains precious and special metals, including gold, silver, palladium and platinum, as well as potentially toxic substances such as lead, mercury, cadmium and beryllium. Therefore, responsible end-of-life management of e-waste is imperative in order to recover valuable components and properly manage hazardous and toxic components. End-of-life management of e-waste includes reuse of functional electronics, refurbishment and repair of electronics, recovery of electronic components, recycling e-waste, and disposal. Reuse, refurbishment or repair of electronic products is most desirable since this option increases the life span of the electronic product and higher resource efficiency. Recycling of electronics allows for precious and special metals to be recovered, reduces the environmental impact associated with electronic manufacturing from raw materials, and ensures that hazardous and toxic substances are handled properly.

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INTRODUCTION

Consumer electronics have become an integral part of daily life and revolutionized the way we communicate, retrieve information, and view entertainment. Between computers, televisions, mobile devices, electronic games, and even devices which measure metabolic rate, it is estimated that the average person owns 24 electronic products (Consumer Electronics Association (CEA, 2008). We live in a society where newer is better, and for each new electronic gadget that reaches the market, one or more becomes outdated or reaches end-of-life. As a result, electronic waste (e-waste), which is defined as any piece of electronic equipment which has reached the end of its useful life, has become the fastest growing component of the municipal solid waste (MSW) stream worldwide. Globally, more than 50 million tons of e-waste were disposed in 2009 and tis number is projected to increase to 72 by 2014.

However, the significant increase in electronic devices has not corresponded to growth in collection, reuse and recycling (Kahhat et al). As technology rapidly advances and electronics reach the end of their useful life at a faster rate, there is a growing need for end-of-life management options. Electronic devices contain up to 60 different elements, many of which are valuable, such as precious and special metals, and some of which are hazardous. Landfilling electronics is undesirable for many reasons, including the fact that trace amounts of precious metals including gold, silver and palladium, and larger quantities of metals and alloys including copper, aluminum, and steel used in electronics are not recovered. Recycling electronics reduces the environmental impact of manufacturing products from raw materials, reduces cost and waste, and also lessens dependence on foreign supplies or minerals and other valuable materials found in electronic devices. However, there are many obstacles to recycling electronic waste, including uncertainty surrounding the end-of-life management of electronic devices, lack of recycling infrastructure, lack of regulatory infrastructure, etc. With the development of technology, the lifespan of electrical and electronic equipments (EEE) is decreasing. The life span of computers has decreased from 4.5 to 2 years in the period 1992 to 2005, thus generating large amount of e-waste to the extent of 20-50 million tones/ year in the world. In India alone, 330 thousand tons of e-waste generated in 2007, which is expected to rise 470 thousand tonnes by 2011. The e-wastes contain valuable, precious and hazardous elements viz. iron, copper, gold, silver, cadmium, mercury etc. In order to meet the environmental norms for hazardous waste disposal and conservation of natural resources around the world, there is a growing concern for the safe recycling of e-waste. Recycling of e-wastes is carried out by the formal and non-formal sectors for the recovery of valuables and disposing of wastes. In India, participation for recycling of e-wastes by non-formal sector is about 95% and that of formal sector is 5%**.** The greater share of unscientific handling of e-waste recycling by non-formal sector causes serious threat to the environment due the emission of dioxine, furan and other harmful gases along with element viz. lead, cadmium, mercury etc. The availability of huge amount of e-wastes and environmental concern attributed development in handling and recycling technology in India and other countries. Some operating or proposed industries for the recycling of e-waste in India are the following companies: Attero Recycling, Delhi, (www.attero.in), Trishyiraya Recycling India Private Limited, (www.ewaste.in), Ecoreco,

(www.ecoreco.com), and E-Parisara, (www.ewasteindia.com) These industries are operating ewaste centers in different parts of India viz. Delhi, Meerut, Ferozabad, Chennai, Bangalore and Mumbai. Various R&D work have been proposed for the development of e-waste recycling processes. In this regard few review papers are also appearing in national and international seminars. Various government organization and research centers are trying to achieve an integrated process for the recovery and separation of metals from the e-wastes including pretreatment process like cutting, shredding, grinding, air classification followed by leaching and solvent extraction process. The processes have also been proposed for the recovery of precious metals such as gold. Researchers and industrialists are integrating together to parleys small scale e-waste recycling industries into large scale industries.

SCENARIO OF E-WASTE IN INDIA

Due to lack of proper technology for the recycling of waste electrical and electronic equipments (WEEE), all around the world, the amount of generation of WEEE is increasing rapidly and comprises about 5% of all the solid waste. In India also demand and supply of EEE increases at a tremendous rate. Fig. 1 shows that there is rapid increase in the number of sales of desktop in the period of 1994 to 2007 and the value reaches up-to 5.52 million. Fig. 2 shows that mobile subscriber in India increases from 90 million to 433 million during the period 2006-11 and expected to touch 900 million in 2015-16.

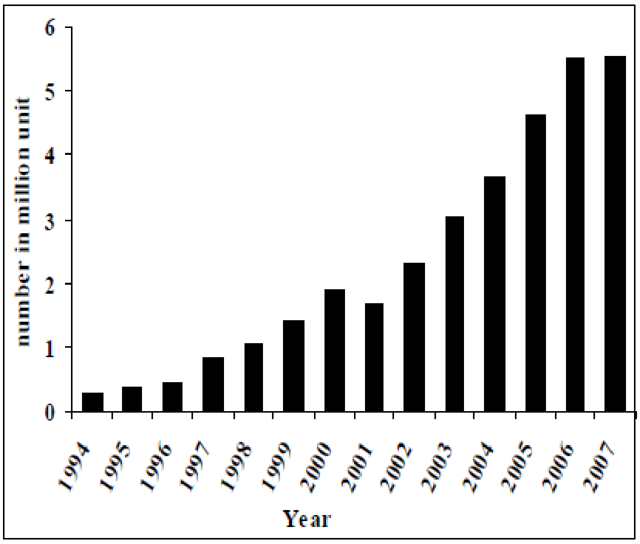

Figure 1. Domestic sales data of electronic devices in India (in million units).

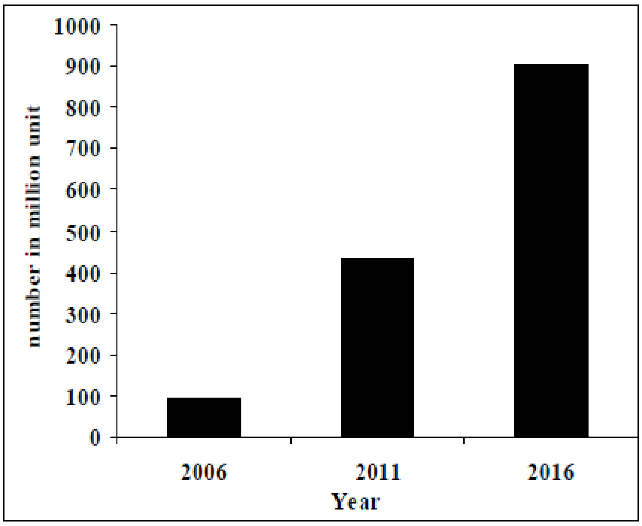

Figure 2. Number of mobile phone subscriber in India (in million units).

Based on the logistic model, it is revealed that around 41-152 million units of computers will become obsolete by the end of 2020. However, total of 2.5 million tonnes of WEEE comprising of PC, television, washing machine and refrigerators are expected to generate during the period of 2007-11. These statistics will help the recyclers in building strategy for the recycling of e-wastes.

REASONS FOR RECYCLING E-WASTE

The driving forces behind recycling e-waste are economic, environmental, public health and data security. A description of these factors can be found below:

Economic Factors- Electronic devices contain up to 60 different elements, many of which are valuable, such as precious and special metals, and some of which are hazardous. Precious metals are rare, naturally occurring metallic elements which traditionally have a higher melting point, and are more ductile than other metals. They have a high economic value, as demonstrated by the two most wellknown precious metals; gold and silver. Special metals include nickel, nickel base alloys, cobalt base alloys, titanium and titanium base alloys. Electronic equipment is a primary consumer of precious and special metals and therefore it is imperative that a circular flow is established in order to recover these metals and valuable elements. Investments are being made to treat e-scrap and reclaim the valuable metals, especially as raw materials become more scarce and expensive. Table 1 below displays the concentration of metals in common electronic products.

Electronic	Copper (% by weight)	Silver (ppm)	Gold (ppm)	Palladium (ppm)
Television (TV) Board(1)	10%	280	20	10
Personal Computer (PC) Board(1)	20%	1000	250	110
Mobile Phone(1)	13%	3500	340	130
Portable Audio Scrap(2)	21%	150	10	4
DVD Player Scrap(2)	5%	115	15	4

Table 1. Concentration of Metals in Electronics

Environmental/Resource Factors- In addition to recovering precious metals, recycling electronics also reduces the environmental impact associated with primary production of electronic products. The primary production of precious and special metals, including energy intensive stages such as mining and smelting, has a significant impact on carbon dioxide emissions. Reuse and recovery of electronics reduces the environmental impact of these products, as well as the impact from primary production of metals and fractions found in electronics.

Public Health Factors- Discarded electronics contain a variety of toxic metals, including lead, cadmium, mercury, chromium, and polyvinyl chlorides, and thus the disposal of electronics poses a significant environmental and health risk when not properly handled. Although e-waste represents less than 2% of landfill mass, it contains 70% of the hazardous waste in heavy metals (Jiang et al). The following hazardous components can be found in e-waste (see Table 2).

Hazardous Component	Electronic Components and Devices
Lead	Cathode ray tubes and solder
Mercury	Switches and housing
Antimony trioxide	Flame retardant
Polybrominated flame retardants	Circuit boards, plastic casings, and cables
Selenium	Circuit boards
Cadmium	Circuit boards and semiconductors
Chromium	Corrosion protection for steel
Cobalt	Structural strength and magnetivity in steel

Table 2. Potentially Hazardous Materials in E-waste.

It is estimated that 50 to 80 percent of e-waste collected in developed nations is exported to developing countries such as China, India and Pakistan due to cheap labor and lenient environmental regulations (StEP, 2009). These developing nations lack the health and safety infrastructure to process and dispose of materials safely, and consequently workers handle toxic metals without proper equipment.

Data Security Factors- Privacy protection concerns have also fueled the processing of electronic waste.

Confidential and personal data must be destroyed properly in order to ensure the safety of organizations and individuals information.

COLLECTION AND RECYCLING OF E-WASTES IN INDIA

Collection of e-wastes - In India, the collection and recycling of e-wastes is largely linked among the manufacturers, distributors, consumers, collectors, traders and recyclers as shown in Fig. 3.

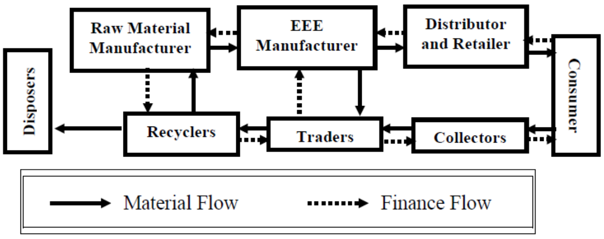

Figure 3. Flow of e-wastes collection for recycling in India.

The unorganized sectors are largely involved in the collecting, trading and recycling works. Unlike developed countries, waste pickers pay price to consumers for their discarded products and there is no concept of Advance Recycling Fee (ARF) which are paid by the consumers to the retailers, retailers to manufacturers and manufacturers to the recyclers.

Recycling of e-wastes - The recycling of e-wastes in India is mainly practiced in unorganized sectors while some industries are also recycling these materials in their plants. In order to develop suitable recycling methods, R & D institutions are also developing processes to recover the valuables to conserve the resources without affecting the environment. The collaborative research in association with foreign research institutions is also being made. These details are discussed below.

a. Industrial approach of Recycling: As mentioned above, the main constituents of e-wastes are plastic, glass and metals. The recovery of metallic constituents is tedious due to presence of various valuable, precious and hazardous metals.

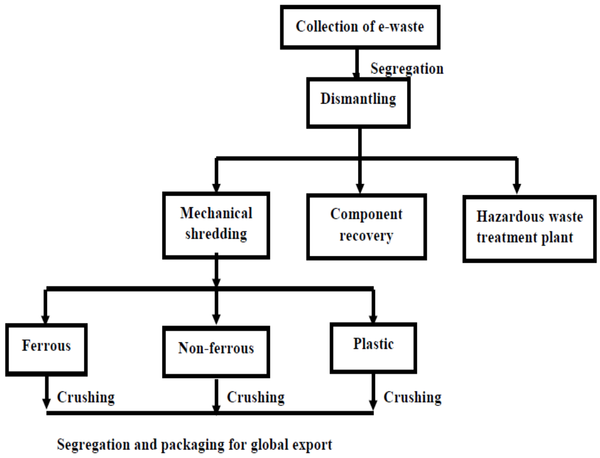

Figure 4. Schematic flow diagram for the recycling of e-wastes in Indian industry.

Some of the industries like Attero, TPL, Ecoreco etc. are involved in the recycling and management of the e-wastes. Fig. 4. depicts typical flow process for recycling of e-scraps in Indian recycling plant. For the better recovery of elements, initially collected e-wastes are segregated according to their parent products followed by dismantling. Components like solder, battery, cables etc. obtained from the dismantling of e-wastes. These components are recycled for the recovery of elements like tin, lead, nickel, lithium etc. The hazardous substances that cannot be recycled are exported to hazardous waste treatment plant. Rest of the part of e-waste viz. plastic, PCBs etc obtained after component recovery undergoes for the mechanical shredding followed by the separation of ferrous, non-ferrous and plastic material. After crushing and segregation of obtained class, these are packed for the global export. Apart from the recycling of valuable and hazardous elements, the segregated constituents are also exported for the recycling of precious metals like gold and silver.

b. R&D studies for recycling of e-wastes: The studies are being made in different R&D institutions. Among them National Metallurgical Laboratory (NML), Jamshedpur is pioneer in developing processes for e-waste recycling, in India. The studies are basically concentrated on physical processing for the segregation and concentration of materials followed by their recovery by hydro/pyro-metallurgical techniques to develop eco-friendly processes. The results of salient processes are described below.

Physical processing of e-wastes: E-wastes are heterogeneous in nature and present in different physical shapes and composition. Different authors made different attempts to classify the ewaste into metallic and non-metallic form by physical processing methods. At NML, physical separation technique has been employed for the beneficiation of metals and other useable components from e-wastes as presented in Fig. 5. E-wastes after dismantling, segregation and shredding are pulverized to a size fraction of 1 to 0.5mm to dislodge the bounded part for downstream process.

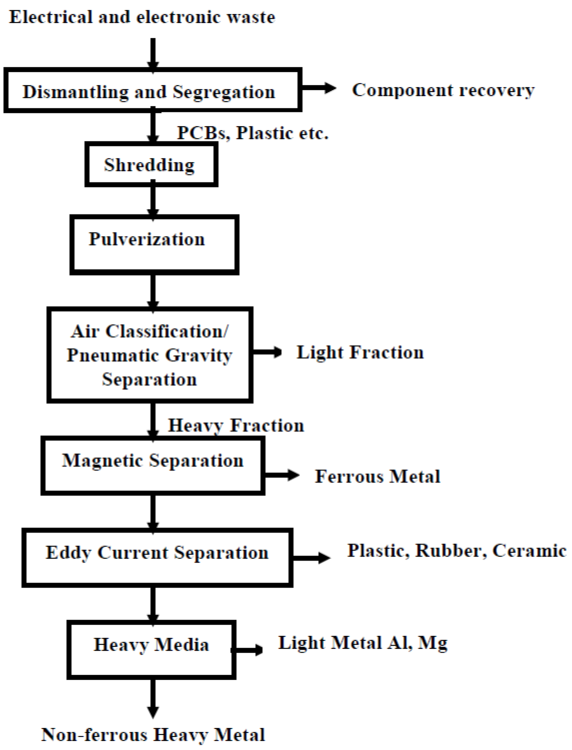

Figure 5. Schematic flow diagram of physical processing of e-wastes.

Pulverized material undergoes for other physical separation techniques based on the physical properties of the material such as density, magnetic susceptibility, electrical conductivity, surface property etc. The pulverized materials are then processed following air classification, magnetic separation of heavy fraction, eddy current separation and heavy media. The product obtained in the process is light fraction (rubber plastics), ferrous metals, ceramics, light metals (Al, Mg) and non-ferrous metals. These separated materials could be further processed to produce valuable products depending on their constituents for certain applications.

Hydrometallurgical Treatment: The metallic fractions obtained after physical processing are further processed for the recovery of valuables following pyro/ hydro-metallurgical routes. Several authors studied leaching, solvent extraction and electro-winning processes for the recovery of valuables in form of metals. The e-scraps are leached for the dissolution of metals present using basic or acidic reagents like sulfuric acid, ammonia, nitric acid etc. Obtained leached solution containing metals undergoes liquid-liquid extraction by the use of organic extractants viz. dialkyl monothiophosphinic acid (Cyanex), di-(2-ethylhexyl) phosphoric acid (D2EPHA), 2-hydroxy-5-nonylacetophenoneoxime (LIX84) etc. for the extraction and separation of metals.

PRESENT E-WASTE HANDLING AND DISPOSAL SCENARIO

In an era of technological advancement the problem of electronics waste (E-waste) management is gradually becoming a global issue [Dasgupta et. al., 2014]. The production rate of Electrical and Electronics Equipment (EEE) is enhancing the business opportunity and also economic growth. Another important issue is EEE manufacturing progress, (i.e. annual generation and growth rate) that can be connected with E- waste generation. Globally, the high obsolesce rate of EEE has always been a serious concern. The replacement market in developed countries is often contributing towards E-waste generation. The scenario is quite different in developing countries where increasing market penetration is the basic rule. Over the years EEE production and waste generation are accelerating because the global and local markets are far from saturation whereas the lifespan of EEE is visibly decreasing e.g. Personal Computer (1997 – CPU lifespan 4-6 yrs; 2005-CPU life span 2 yrs.).

Global E-waste generation was nearly 20-50 MT/yr in 2006 and noticeably increasing (~ upto 1.0MT/yr) of the generated solid waste. Organization for Economic Cooperation and Development (OECD) study predicts that E-waste generation will be as high as 9.8 MT/yr (2015) and growth rate is 0.86 % (base year 2010) [Cobbing , 2008].

In India, E-waste is being generated rapidly due to increased consumption behavior. However, both the consumption and waste generation pattern are different as they primarily depend on life style and economic strength. The collection, recycling and disposal of E-waste are governed by the traders where Local Small E-waste Dealers (LSEWD) play a vital role in handling of E-waste. The Large E-Waste Dealers (LEWD) are dependent on these LSEWD. The auctions for non-household generated E-waste are arranged for sale in both private and government sectors. The chain is complex and it normally operates on the basis of economics of the E-waste. Finally the collected E-wastes are dismantled, segregated and market demand portions are recycled. The utilization of the recycled E-waste is solely dependent on the nature and the type of the materials and their market values [Betts, 2008]. The principal characteristics of E-waste are different from other forms of waste (both municipal and industrial) and have distinctly different physical and chemical properties**.** E-wastes mainly have both precious and hazardous metals and materials as constituents that should be dealt carefully during handling. This regulated practice (collection, dismantling, recycling and disposal) will help minimizing and may even avoid environmental contamination, caused by different hazardous substances. The most important and serious concern is the exposure of toxic materials to humans particularly to the waste handlers. The useful component of the E-waste management is the recycling of the secondary raw materials, provided the toxic components have to be taken care of. The major lacuna in the current Indian E-waste management practice is the "Systematic and scientific" handling of E-waste. The complexity in nature and type of EE appliances and rapid variability in composition including addition of new items makes it difficult to handle E-waste efficiently for recycling and reuse purpose by the Indian E-waste managers (LSEWD and LEWD) [Wath et al.,2011]. Nevertheless, a legal mandate is often helpful to encourage recycling and reuse of E-waste that have been practiced by the developed countries in several ways (Basal Convention, NEAP, EPR, ARF) .

Of late, India has implemented a comprehensive rule in the form of "E-wastes Management and Handling Rules, 2011" which has been effective from 1st May 2012. Existing informal E-waste management practice is the pressing issue and concern for both human and environment. The time scale demands a switching over from informal to formal sector of E-waste management and the mechanism of the governance is the key factor for implementing a sustainable E-waste management scheme though it requires few decades with several modifications in the legal frame work. The present paper focuses on a roadmap for the E-waste management system after reviewing the current situation of E-waste generation, operation and recycling practice. A bridge has been put forward to make systematic and scientific plan to reduce the impact of major issues and concern of trade chain of E-waste. A summary of legal framework has also been outlined to highlight its importance for E-waste recycling.

CONCLUSION

E-waste is one of the fastest growing solid municipal wastes in India. Out of 20-50 million tons of e-waste being generated in the world, it is estimated that India will alone generate 4.7 hundred thousand tones by the end of 2011. E-waste collection, trading and recycling are mostly carried out by unorganized sectors. Only 5% of the total e-waste being generated is recycled by the formal sectors, while large involvement of non-formal sector may cause threat to the environment. E-wastes contain hazardous, valuable and precious metals. In general, the e-waste comprises of 30% plastics, 30% refractory, and 40% metals. Most of the Indian recycling companies are treating e-waste up-to pretreatment stages only. Considering the depth of this problem, government is serious to implement law, administrative procedure, ban on imports and export of hazardous materials, identification of components containing toxic materials collection of e-wastes from manufacturers/ consumers, incentives for their collection, awareness programs, etc. The Indian R&D work related to e-waste recycling is directed towards the development of feasible process consists of mechanical pre-treatment and pyro/ hydro-metallurgical techniques.

Several researchers reported bench and pilot scale studies for recycling of e-waste using mechanical/ organic pre-treatment processes followed by leaching, solvent extraction and electro-winning. Eco- friendly and energy-saving processes are necessary to comply with stringent environmental regulations.

Despite the many reasons to recycle e-waste, U.S. recycling and recovery of e-waste is limited due to: (1) insufficient collection (2) no Federal legislation or policy mandating e-waste recycling (3) lack of recycling and recovery technologies and (4) illegal exports of hazardous ewaste to developing countries where recycling processes pose serious risks to human and environmental health.

In India, E-waste handling, trade chain and recycling are in primitive stages whereas the E-waste generation rate is increasing in various sectors due to over-usage of both major and minor EEE. The clear understanding of the composition of E-waste is an important prerequisite and effort has to be made to register the growth of individual components (viz. Glass, Plastic, Ferrous, Non-ferrous etc.) so that generation, disposal and recycle can be done in scientific and systematic way. Various issues and concern are now associated with E-waste generation and handling, particularly for metal and plastic components the scenario is reasonably alarming. Several regulations now exist both in national and international arena to control the bulk generation of E-waste. India has already formulated E-waste regulation (E-waste Management and Handling Rules, 2011) to evade uncontrolled E-waste generation. To cope with the situation a management plan is essential and thus has been proposed, where multistep and multistage approaches have been emphasized. Implementation of such E-waste management plans will definitely improve the current uncontrolled situation and also will ensure transformation of informal sectoral practice to its formal counterpart in the domain of E-waste management.

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