

**Review Article**
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## Effective Utilizations of Red Mud with Emphasis on Circular Economy

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**ABSTRACT**

Red mud (Bauxite residue) is an industrial by-product (IBP) generated as a vast volume, mainly from aluminum industries. Disposal of red mud (RM) in open land leads to serious environmental hazards, occupies a vast land area, and incurs enormous economic and social costs. Storage and maintenance of red mud dumps are also costly, and their failures frequently flood vast areas, killing people and cattle and disrupting the ecosystem. Conversely, research data shows that the red mud has enormous potential to transform its valuable resources. Due to the growing demand for bauxite ore for aluminum industries, the volume of red mud has been increasing rapidly, causing an inevitable multidirectional consequence in the context of environmental and sustainability issues. On the other hand, the rising demand and resource crises continue to deplete natural resources; the gap of enormous resource availability has become a severe challenge for scientists, researchers, and institutional R&D to develop a process technology to re-generate resources through the recycling of wastes. Using red mud through the circular economy concept can replenish the depletion of virgin resources (mainly the construction sector) and extract valuable materials and metals from red mud. Recycling RM through the circular business model can increase the sustainability of natural resources, reduce environmental pollution, water contamination, and land pollution, increase land area, replenish the depletion of natural resources, enhance economic growth, and mitigate global warming and climate change.

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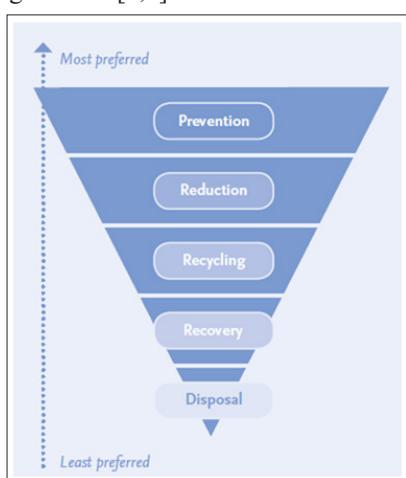
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**Introduction**
**The Transition from Linear to Circular Economy**

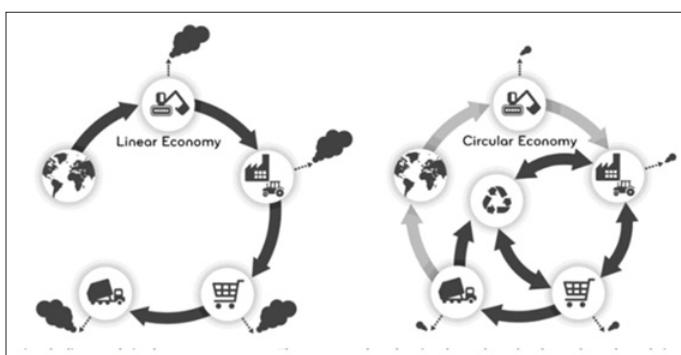
Globally, interest towards applying of circular economy concept has surged in recent years, reflects new direction of research about wastes and the utilization of resources, it emerges the waste hierarchy (Figure 1) and aim on higher order uses, while developing on the idea of continually reusing, recycling and recirculating of IBPs [1,2].



Recent endeavour to foster the concept of transition from waste to wealth and linear economy to circular economy have been manifested new direction to the Scholar, R&D experts and entrepreneurs to explore innovative idea to develop process technology to transform IBPs to a valuable product, which can be replenish the depletion of natural resources through the process of recycling [3-6].

In the process of linear economy, notion is that there is a continuous supply of natural resources for the processing of products, and after use, it has been disposed as a post-consumer waste, these wastes incurs enormous amount of environmental, economic, and social cost. A circular economy has been propounded as a sustainable substitute to our present linear economic model, mainly by recycling and recirculating IBPs, post-consumer waste and discarded materials for the purpose of development new products, main focus on recirculation of resource in circular economy loop is to conserve value proposition as much as possible [7]. To make sustainability in natural resources and to prevent global population go to waste, we must “closing the circularity gap” as a model of circular economy instead of linear economy model. Figure 2 presented a graphics of “Linear Economy Vs Circular economy”.

**Figure 1:** The Waste Management Model (Source: UNEP, 2011. Towards a Green Economy)



**Figure 2:** Graphical flow Line “Linier Economy Vs. Circular Economy” (Source: [8])

Circular economy processes may be an integrated process for synergistic reutilization of Bauxite residues (Red Mud). Bauxite residue (Red Mud) despite of waste, it may be a valuable input material for other products purposes if we can process it with the proper scientific way, on the other hand it may call as a “by-product of economic activity” [9-15].

Initiatives towards a more circular economy could deliver several advantage and benefit such as Increasing security of resource, replenish the depletion of natural resources, reducing GHG, decreasing waste volume, boosting economic growth and others benefit including employment opportunities and increasing competitive advantages for companies and leading to increase global sustainability [5,8,16,17].

Australian Government has published five principles on “Applying circular economy principles for waste, recycling and resource recovery” which is available in the source as (Source: Australian Government, National Waste Policy, Department of the Environment and Energy, 2018).

### Global Perspective

Globally, the drives of manufacturing lightweight components in the automobile industry to increase fuel efficiency and reduce CO<sub>2</sub> emission as well as other relevant uses has led to much wider use of aluminium. [18-21]. Global primary aluminium production in 2018 was 65 million metric tonnes, [22].

Due to the growing demand for aluminium globally, the total volume of aluminium smelting crossed 60 MT in 2018 and subsequently, the bauxite demand also increasing substantially [23]. Global productions of bauxite country-wise from different sources are summarized in Table 1

**Table 1: Country-Wise Bauxite Production (2013 & 2014)**

Country	Mine production (X1000 tonne)		Reserves
	2013	2014	
Australia	81,100	81,000	6500,000
Brazil	32,500	32,500	2,600,000
China	46,000	47,000	830,000
Greece	2,100	2,100	600,000
Guinea	18,800	19,300	7,400,000
Guyana	1,710	1,800	850,000
India	15,400	19000	540,000
Indonesia	55,700	500	1,000,000
Jamaica	9,440	9,800	2,000,000
Kazakhstan	5,440	5,500	160,000
Russia	5,320	5,300	200,000
Suriname	2,700	2,700	580,000
Venezuela	2,160	2,200	320,000
Vietnam	250	1,000	2100,000
Other countries	4,570	4,760	2400,000
World total	283,000	234,000	28,000,000

(Source: [24])

Globally, approximately 117 million tons of RM is generated annually [25]. Disposal of RM causing serious hazards. Utilization of RM as construction material such as backfilling, road construction, cement production, brick & concrete, tiles, aggregates and recovery of rare earth & valuable metal, etc. seems inevitable [26-36]. Table 2 presented the resource status and inventory of eight major bauxite producer country.

**Table 2: Country-Wise Production of Bauxite, Alumina, and Aluminium Smelter**

Country	Bauxite (Tonne)	Alumina (Tonne)	Reserves (Tonne)	Aluminum Smelter (Tonne)	Aluminum smelter year-end capacity (Tonne)
China	68,000	72,300	1,000,000	32,600	44,500
Russia	5600	2800	500000	3600	3900
India	27000	6170	830000	3200	3600
Canada		1570		3210	3270
USA		1500	20000	740	20000
Australia	83000	20600	6000000	1490	1720
Norway				1220	1550
Brazil	36000	11000	2600000	800	1400

(Source: [37])

Research finding of red mud studies shows that it is very suitable and worthy for recycling or reuses as a raw material in a wide range of commercial and other relevant applications using cost-effective procedures [38-43]. Table 3 presented the utilization of RM in various applications (worldwide).

**Table 3: Utilizations of Red Mud (worldwide)**

Description	References
Extraction and Recovery of Valuable Metals [SiO <sub>2</sub> , CaO, Fe <sub>2</sub> O <sub>3</sub> , Al <sub>2</sub> O <sub>3</sub> , Na <sub>2</sub> O, TiO <sub>2</sub> , K <sub>2</sub> O]	[41] [44] [45]
Recovery in Component in RM	[46,47]
Recovery of Rare Metals from RM	[48-50]
Production of Construction material from Red Mud	
Geopolymers	[51,52] [53]
Clay-based products	[54,55]
Cement	[56,57]
Brick	[58,59]
Glass	[60,61]
Aerated concrete block	[62]
Utilization of RM as filling materials	
Road base materials	[43]
Mine filling	[63]
Application in Pollution control	
Wastewater treatment	[64,65]
Soil improvement by Red mud	[66,67]
Treatment of waste gas containing sulphur by red mud	[68]

Many R&D organizations have been evaluated the different applications of red mud and gained global acceptance. Between 1964 and 2008, **734 patents** have been registered for utilizations of red mud for various applications worldwide [25,69-71], summary of the registered patent presented in Table 4.

**Table 4: Red Mud Applications: Registered Patents (1964-2008)**

Red mud applications [25]	
Civil construction	33%
Water treatment	13%
Soil treatment	12%
Ceramic composition	12%
Recovery of metals	11%
Additive for metal production	7%
Gas remover	4%
Adsorbents	4%
Others elements	4%

(Source: [25])

### The Disposal of Red Mud and its Environmental Impacts

Worldwide, aluminium industries are facing major challenges with the storage and disposal of red mud. Presently dry stacking method considering as secure disposal of the red mud with the constraint of land requirements scenario [72,73]. Damaging effects of red mud waste on the environment and ecology are quite extensive, dumping of red mud occupies the vast land area, polluting land, air, and groundwater respectively [73-77]. Maintaining of storage dam for red mud is costly and their failures frequently flood vast areas, killing people, cattle, and disrupting the ecosystem [78,79]. Table 5 presented few serious incidents due to the storage systems of Red mud waste in open land and the dam respectively.

**Table 5: Red mud Incidents in Different Countries**

Date	Place	Incident
26-May-2012	Guangxi Huayin, China	Leaking of disposal pond
12-Jan-2012	Rusal, Ireland	Fine dust contamination
10-Dec-2011	Alcoa, Virgin Island	General pollution
17-Oct-11	Venezolana de Guayana, Venezuela	Red mud discharge into Orinoco River
2-Jun-2011	Rusal, Italy	Spills of red mud
16-May-2011	Vedanta, India	Pollution after heavy rain
3-Mar-2011	Rusal, Ukraine	Fine dust contamination
22-Oct-2010	Alcoa	The United States Fine dust contamination
4-Oct-2010	MAL Hungarian, Hungary	Dam break
27-Jun-2010	Vedanta, India	Fine dust contamination
1-Feb-2010	Rusal, Jamaica	Clouds of toxic dust
27-Apr-2009	Norsk Hydro, Brazil	Red mud discharge into Murucupi river
20-Aug-2008	Rio Tinto, Canada	Red mud discharge into the river
21-Feb-2008	KAP Aluminum	Montenegro Fine dust contamination
6-Apr-2007	Rio Tinto, Canada	49 tonnes released into Saguenay River
14-May-2006	Alcoa, Australia	Poisonous dust emission
6-May-2002	Alcoa, Australia	Disposal of red mud onto local farmland
1966-Present	Rio Tinto, France	Red mud discharge into the ocean

(Source: [35,80])

### Chemical Compositions of Red Mud

Properties of red mud are mainly dependent on the category of bauxite ore using and refining processes. For several considerations, the Red mud appears to be potential resources for various applications and alternatives. Chemical composition is one of the important considerations to determine the utilization pattern of red mud in different applications and uses respectively. Chemical compositions of some RM from different companies are presented in Table 6 respectively [81].

**Table 6: Chemical Composition of RM from Different Companies' Worldwide**

Composition (%)	ALUNORTE	ALCOA	CBA	ALCAN	ALCOA	ALCAN
	Brazil	Brazil	Brazil	Canada	Australia	Africa
Al <sub>2</sub> O <sub>3</sub>	35,5	35,67	36,7	37,6	25,45	26,6
Fe <sub>2</sub> O <sub>3</sub>	37,16	33,78	29,89	32,45	34,5	48,4
SiO <sub>2</sub>	2,34	3,45	6,78	3,67	17,06	5,5
TiO <sub>2</sub>	6,18	4,56	5,67	4,12	4,9	2,8
Na <sub>2</sub> O	8,49	9,67	7,89	6,78	2,74	2,4
CaO	1,23	2,34	1,2	3,45	3,69	-

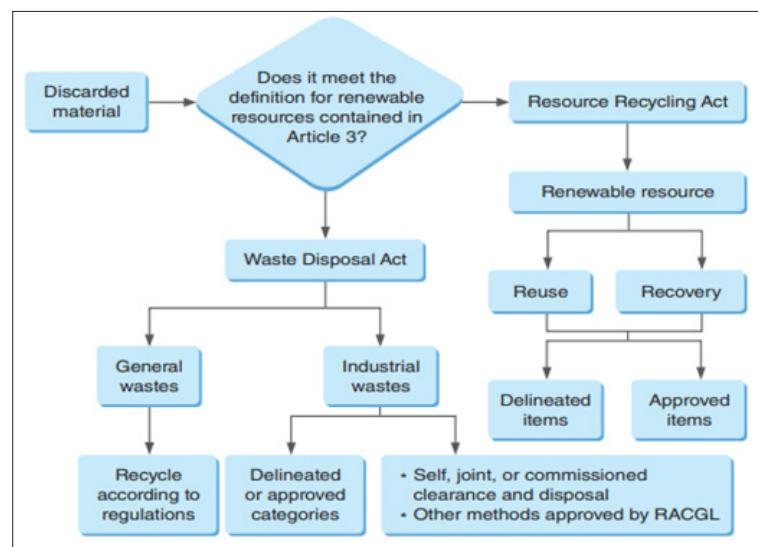
(Source: [25])

### Policy Relevance in the Current Context

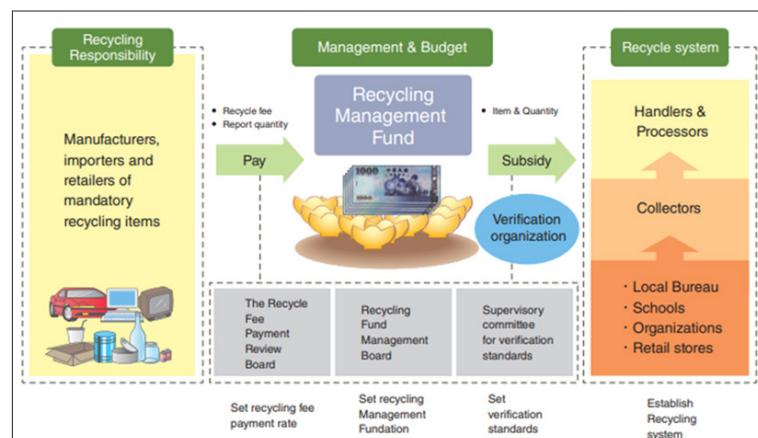
The right model for policy and regulatory framework pertaining to managing IBPs is an urgent need at the national and state level. Various countries have taken lot of initiatives to form different of policies and guideline for managing waste.

In the year of 2013, Asian Productivity Organization (Resource recycling in R.O.C, 2013) has been published a report on policy implementations by Taiwan Government on “Utilization of Industrial waste” has described following two major concept on managing Industrial waste through a proper flow chart are as follows

- The best practices and policy implementation for recycling Industrial by products (IBPs) (Figure 3)
- Operation of resource recycling management fund presented (Figure 4)



**Figure 3: The Process for Identifying the Relevant Regulations for Recycling Industrial Waste**  
(Source: Asian Productivity Organization. Resource recycling in R.O.C, 2013)



**Figure 4: Operation of Resource Recycling Management Fund Presented**  
(Source: Asian Productivity Organization. Resource recycling in R.O.C, 2013)

## Discussion

Recycling and utilization of bauxite residues should be a part of the vision towards sustainable development, but it needs action. Innovative approaches towards IBPs management are a part of the sustainable solution but we will not succeed if the associate, responsible and concern actors work jointly towards aim of sustainable development.

To get succeed, actors all along the systems of IBPs management will have to co-operate each other's for the sake of sustainable development reach to a mission of zero waste. Only at that point will we achieve meaningful positive impacts.

With the holistic vision and cooperation among Government, R&D partner, industry, public and private sector, bauxite residues (IBPs) can be managed more efficiently and effectively. Through collaboration and cooperation, new concept of business models (with the coupling of circular economy) and incentives can be enhance the process to maximize value from recycling of IBPs, leading to expanded and robust markets for products and resources recovered from bauxite residues (IBPs). Creating common platforms for collaboration, cooperation and technology & knowledge transfer, best practices can be adopted and implemented. This Joint and collaborative action plan leading to a way forward for innovative and sustainable approaches for recycling and utilizations of bauxite residues (IBP) [82-114].

## Conclusion

Mission zero waste challenges all stakeholders to eliminate IBPs through recycling and recirculation by coupling the circular economy model. This pushes them to redesign their existing practices, policies, and norms and direct them towards greater sustainability. The adequate disposal and storage of bauxite residues (red mud) from aluminum industries remain challenges for both corporations and the government; it is probably a direct consequence and impact of inadequate practices long past for managing IBPs, which in turn produced a negative impact on environmental, ecology and economy as well. Recycling bauxite residues (red mud) through the circular economy model can partially replenish the depletion of virgin resources, reduce pollution, increase land area, and improve sustainability.

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