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Feasibility Assessment for Adoption of Circular Economy Model in Steel Industry

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Abstract— Circular economy is basically a model that leads to optimum utilization of resources which is aimed at eliminating waste and continual use of resources. Adoption of circular economy has substantial benefits in terms of innovating new products and services from used one. It has great access to market as well creates great oppourtunity for corporation and collaboration for manufacturing new products from used one. This in turn improves environmental performance and reduces the risk of shortage of resources. It is a new manufacture and utilization model that ensure sustainable development over time. Until now we have lived with linear production model to extract, produce, consume and discard. In this manufacture and utilization model, raw materials are used repeteadly to produce new products. In circular economy raw materials are kept longer in production cycles. The transition towards circular economy has become the need of the hour. The shift towards circular economy has great potential to expand even by starting small. To reap maximum benefits from circular economy, closed loop materials and energy flow needs to be implemented. Hence this is the hour of need for steel industry must pay attention for adoption of circular economy to the fullest. As what goes around comes around, so whatever was once old will be new again.

Keywords— Circular Economy, Steel Industry, Sustainability

I. INTRODUCTION

Steel industry generates various sorts of dust, sludge, mill scales or by-products etc as a waste in significant amount in day to day operations. These wastes contain a considerable amount of valuable minerals or metals. It is advantageous to recover the valuable minerals present and utilize these wastes. There are ways to recover these minerals/metals through sintering process [1]. World economy is built on linear economic mode, i.e; take, make and dispose. We take raw materials from mother earth, make products from those raw materials and finally dispose them. In this process resources are depleted continuously, generation of waste increases which in turn affects the environment. With the rate of depletion of raw materials it is envisaged that we may run out of resources such as iron ore within 50-100 years [2]. With increase in industries there is increase in exploitation of resources and destruction of environment which forced industries and production system to undergo an intensive transformation. These transformations are forcing industries to look way forward for the adoption of sustainable practices [3]. The idea of a "circular economy" is emerging as a solution to these problems. The World Business Council on Sustainable Development (WBCSD) has adopted a circular economy as for the mission for its Vision 2050. Circular economy is basically a model that leads to optimum utilization of resources which is aimed at getting rid of waste and repeated use of resources. This is a new manufacture and utilization model that ensures sustainable development over time. A circular economy brings new value added products. It also helps in recycling waste within the economy. Circular economy ensures that any product, after reaching its end of life, gets recycled in such a way that it can be used again and again productively. As shown in Figure 1, a product may be reproduced from recycled, refurbished or used material in such a manner that it does not lose its value.

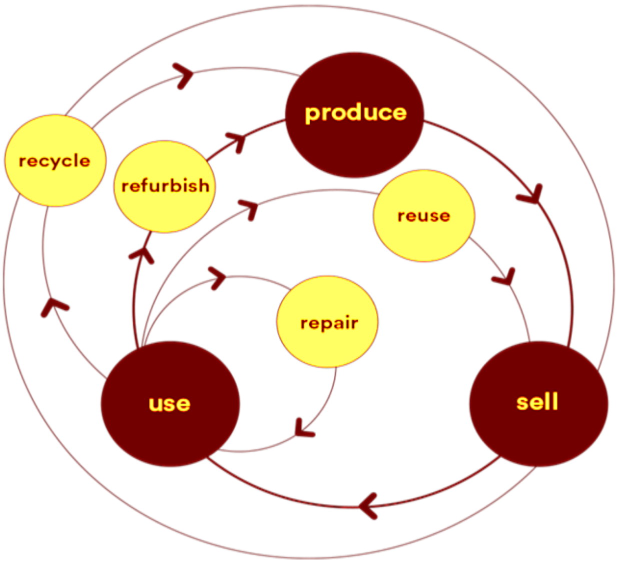


Figure 1. *Circular Economy diagram*

Joining hands with Government of India (GoI), steel industry is also leading towards achieving circular economy. Heading towards reducing carbon footprint will require transformation in the process of iron and steel production [4]. This study is important because steel plant waste generated from various shops usually contains considerable amount of reusable minerals. These minerals are usually recoverable by means of physical or chemical mineral processing techniques such as crushing, grinding, classification, hydro-cyclone, magnetic separation, froth-flotation, leaching or roasting. Recovering valuable minerals from steel plant waste by use in same production unit or by other industrial installation is not only the need of the hour for conserving metals and mineral resources but also for protecting the environment [5]. During 2020-21 India's GDP shrink by 7.3%; for revival of economy government is continuously working out schemes such as Atmanirbhar Bharat, Vocal for Local, etc. Also, government has framed some policies such as plastic waste management rule, e-waste management rule, construction and demolition waste rule, medical waste management rules, etc. The transition towards circular economy has become the need of the hour.

This paper discusses about the steel plant process as well as waste generation and consumption pattern in steel industry. Also, it focuses on the idea and benefits and challenges associated with adoption of circular economy in steel industry. Rest of the paper is organized as follows, Section I contains the introduction of circular economy and its importance in steel industry. Section II contains the related work in the field of circular economy as well as categorization of various steel industry wastes. Section III presents the way of utilizing these wastes so that it can return in the production system. Section IV concludes research work with future directions.

II. RELATED WORK

Generation of waste as per world waste facts, the world counts (2017) is 2.1 billion tons. This amount is expected to triple by 2100. Steel industry is also one of the industries which generates huge amount of waste. The chemical composition of various waste materials generated at an integrated steel plant is given in Table 1. 16 types of plant waste were analysed using XRF. Valuable minerals along with their quantity present in these wastes are shown in the Table 1.

Table 1: Typical plant wastes of an integrated steel plant

Sl. No.	Waste	Fe_2O_3 %	SiO_2 %	Al_2O_3 %	CaO %	MgO %
1	BF Slag	0.08	37.20	26.02	28.78	6.03
2	BF ESP dust	74.41	8.30	3.21	2.23	0.71
3	BF Flue Dust	39.07	9.06	4.42	5.31	0.67
4	BF Sludge	39.93	9.50	5.74	5.28	1.02
5	Sinter Dust	70.66	5.56	4.78	8.34	5.22
6	Mill Sludge	97.07	1.13	0.27	0.13	0.18
7	Mill Scale	88.08	8.61	1.28	0.26	0.16
8	BOF ESP Dust	64.37	4.39	0.76	12.94	3.92
9	BOF Sludge	61.37	4.54	0.70	25.01	3.95
10	BOF Slag	23.57	14.79	0.27	45.24	5.50
11	BOD Sludge	1.46	0.92	0.45	0.70	0.14
12	WTP Sludge	7.94	20.73	30.45	2.49	0.70
13	Dolo-dust	0.61	0.69	0.26	51.40	25.00
14	Lime-dust	0.28	0.71	0.02	87.25	2.98
15	CO-CDU dust	12.91	23.97	10.07	3.65	0.38
16	CO - CDCP dust	6.07	10.48	4.68	1.32	0.18

These wastes also contain some harmful components like oxides of Pb, Zn, P etc. which are highly unacceptable from the pollution as well as Blast furnace (BF) operation point of view. Therefore, the disposal of these wastes will occupy adequate land as well as causes ecological imbalance and also increases the disposal costs. A typical analysis of harmful components of steel plant waste is given in Table 2.

Table 2: Harmful components in typical plant wastes

Sl. No.	Waste	SO_3 %	P_2O_5 %	Na_2O %	K_2O %	ZnO %	PbO %
1	BF Slag	0.63	0.00	0.26	0.37	0.00	0.00
2	BF ESP dust	1.32	0.18	0.30	0.44	0.01	0.00
3	BF Flue Dust	1.03	0.28	0.10	0.29	0.02	0.00
4	BF Sludge	1.28	0.25	0.28	1.53	0.49	0.35
5	Sinter Dust	0.40	0.14	0.07	0.12	0.00	0.00
6	Mill Sludge	0.10	0.08	0.07	0.02	0.00	0.00
7	Mill Scale	0.14	0.08	0.20	0.27	0.00	0.00
8	BOF ESP Dust	1.81	0.20	0.24	0.49	0.04	0.00
9	BOF Sludge	0.56	0.22	0.10	0.10	0.02	0.00
10	BOF Slag	0.07	1.31	0.00	0.05	0.00	0.00
11	BOD Sludge	5.10	0.02	1.10	0.23	0.02	0.004
12	WTP Sludge	1.19	0.28	0.11	0.44	0.02	0.01
13	Dolo-dust	0.14	0.02	0.02	0.03	0.00	0.00
14	Lime-dust	0.00	0.00	0.00	0.04	0.00	0.00
15	CO-	7.96	0.73	0.19	1.49	0.04	0.00

	CDU dust						
16	**CO - CDCP dust**	4.62	0.31	0.10	0.66	0.02	0.00

Table 3 shows trace elements present in the steel plant waste. Loss on Ignition (LOI) of these waste are also given in the table.

Table 3: Trace elements and LOI in typical plant wastes

Sl. No.	Waste	ZrO_2 %	Cl %	MnO %	TiO_2 %	Cr_2O_3 %	LOI %
1	BF Slag	0.00	0.00	0.07	0.47	0.00	0.00
2	BF ESP dust	0.006	0.29	0.10	0.16	0.04	8.30
3	BF Flue Dust	0.01	0.06	0.09	0.26	0.03	39.24
4	BF Sludge	0.01	0.06	0.08	0.21	0.02	33.93
5	Sinter Dust	0.00	0.02	0.07	0.22	0.03	4.37
6	Mill Sludge	0.00	0.00	0.90	0.00	0.04	0.00
7	Mill Scale	0.00	0.00	0.83	0.05	0.05	0.00
8	BOF ESP Dust	0.00	0.10	4.44	0.19	0.03	6.06
9	BOF Sludge	0.001	0.02	0.33	0.18	0.03	2.84
10	BOF Slag	0.00	0.00	0.83	0.97	0.08	0.00
11	BOD Sludge	0.00	0.81	0.02	0.04	0.01	88.14
12	WTP Sludge	0.00	0.04	0.26	0.024	0.02	34.69
13	Dolo-dust	0.00	0.02	0.05	0.00	0.00	21.73
14	Lime-dust	0.00	0.00	0.01	0.00	0.00	8.23
15	CO-CDU dust	0.00	0.15	0.13	2.21	0.26	35.16
16	CO - CDCP dust	0.00	0.08	0.04	1.18	0.16	69.80

So, it is advantageous to recover the valuable minerals and utilize these steel industry wastes. However, it is not easy to recover directly these minerals. Therefore, detailed scientific investigation is necessary to ascertain the scope of the problems associated with recovering the valuable materials from these industrial wastes and the proposed utilizations are to be carefully evaluated.

Use of fly ash and slag produced in steel industry towards value product production could be a major step towards achieving zero waste and reduce environmental footprint. These wastes can also be recycled in-house for production of agglomerates. Recycling the waste for material recovery is a widespread practice by steel industry. As resources are used repeatedly rather than being depleted, the ultimate destination of a product is not waste but a further product. Steel is a reasonable material for the circular economy era.

Steel industry has already framed a policy on sustainable development which is backed by its contribution towards a clean and sustainable environment. Steel industry is committed to create a positive footprint with society [6]. Steel industry has adopted many energy efficient technologies such as waste heat recovery in sinter plant and BF stoves, coke dry quenching, Bell Less Top (BLT) equipment, Top recovery turbines (TRT) in BF's and CO_2 emission mitigation strategies such as energy monitoring and management system, regenerative burners in reheating furnaces, hot charging process of cast products, Pulverized coal injection (PCI) in BF, adoption of variable voltage variable frequency (VVVF) drives for high capacity electric motors, switching over to energy efficient LED lights, Enhancing BOF gas recovery and use in downstream facilities, 100% online metering and monitoring of all forms of energy, etc. which in turn reduce specific energy consumption by 3.7% and specific CO_2 emission by 12.7% in last 10 years. TRT is basically an energy saving measure which utilizes the waste pressure energy of BF top gas to generate electricity which helps in bring down the energy consumption and reduce GHG emissions. Steel industry is in continual improvement for environmental performance indicators over the previous years. Over the last three to four decades steel industry has been trying to minimize energy use and environmental pollution associated with manufacturing of steel.

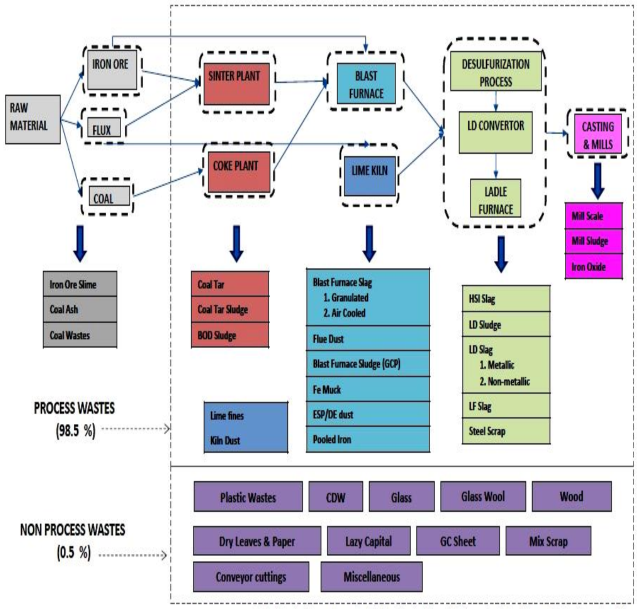
Inline to achieve circular economy, Steel industry has adopted "4R's policy" across all its process. With Reduce, Recover, Recycle and Reuse; Steel industry is committed to reduce solid waste generation and maximize its utilization. Scarcity of resources and environmental impact of economic activities are two major enablers which make us to think for green steel production. Steel industry also carried out drive for reducing specific water consumption. Conservation of water has become priority in steel industry and several measures are being taken in plants as well as mines to improve water recirculation and to achieve zero liquid discharge. Steel industry is also working towards restoration and rehabilitation of degraded ecosystem. Extensive afforestation program is being run across steel industry plants and mines. Digital transformation at steel industry and engineering innovation has been key enablers for strengthening of policies for circular economy. Digital technologies has enabled steel industry to collection of massive amount of data and resource flow which can be easily managed through innovative technologies such as machine to machine communication, mobile, cloud computing, big data analysis etc. Digital transformation is laying fundamental basis for transition towards a circular economy. Use of digital, online platforms and technologies that provide insights to track may help in optimising resource mobilization between supply chain systems. In addition many other circular economy business models are being implemented and developed. Promotion of renewable energy is also can be major contributing area towards adoption of circular economy. Afforestation for creation of carbon sink by promoting planned plantation of 5 lakh trees per year also in the book of steel industry.

Achieving 100% capacity utilization of all existing facilities will also contribute in achieving the energy efficiency target. It is felt that sustainability is expensive in present environment, but in reality waste is more costly as it uses more resources than required to dispose it safely as per stringent environmental law. In circular economy waste is regarded as resources itself and thus it reduces the need to continuously extract more from mother earth.

III. RESULTS AND DISCUSSION

Steel industry comes in one of those essential industries which count for the development of any country. Steel industry is also considered as base industry without it several industries could not even established. Process of an integrated steel plant is shown in figure 2.

The process shows various waste generations from different shops. Iron ore slime, coal ash and coal wastes are generated from raw material handling system of an integrated steel plant. Similarly, coal tar, coal tar sludge and BOD (Biochemical oxygen demand) sludge is generated from cove making process. Air cooled slag, flue dust, Gas cleaning plant sludge, electrostatic precipitator plant (ETP) dust, etc. are generated from Blast furnace iron making process. Steel making slag, LD sludge, Ladle furnace slag and steel scrap are generated from steel making process. Mill scale and mill sludge are generated from casting and rolling process [7].



BOD: Biological Oxygen Demand; GCP: Gas Cleaning Plant; ESP: Electro Static Precipitator; DE: Dust Extraction; HSI: High Sulfur Iron; LF: Ladle Furnace; CDW: Construction & Demolition Wastes

Figure 2. Process of an integrated steel plant with waste generation

Steel industry waste has captured ample amount of land which could be used for more useful purposes. The disposal of these wastes will also occupy plenty of land as well as causes ecological imbalance and also increases the disposal costs. Also, with regulatory norms becoming more stringent, it is being more difficult to continue the practice of dumping the waste at dumping sites. It is clear that resources are no longer cheap and abundant. Therefore, it is advantageous to recover the valuable minerals and utilize these steel industry wastes. Solid wastes generated from other shops of steel plant such as mill scale, flue dust, used refractory bricks etc. can recycled inside as well as outside plant. Installation of micro-pelletization plant/briquetting plants for reuse of all recyclable waste along with crushing and sizing facilities will be gainful. Scraps produced from mills are also being utilized as chiller in BOF fulfilling the requirement of steel making. Metal recovery after proper sizing and segregation from BOF slag will be another area to increase the recyclability of steel. Yet slowly but steel industry is moving towards the concept of zero waste generation. Slag generated from blast furnaces (BF) and basic oxygen furnaces (BOF) are two major contributors for solid waste generation. BF slag is utilized by granulating it; almost 99% of granulated BF slag is utilized in cement manufacturing as a substitute of clinker [8]. However, possibilities are being explored for utilization of BOF slag in paver block making, as a substitute of railway ballast, rural road making and for treatment of soil. Possibility for use of plastic in coke making as well as in BF is also being explored. Apart from this, a part of BOF slag is being utilized in sinter making fulfilling the concept of circular economy. Therefore, protection of environment is one the greatest benefit of circular economy.

Adoption of circular economy has substantial benefits in terms of innovating new products and services from used one. It has great access to market as well creates great opportunity for corporation and collaboration for manufacturing new products from used one. This in turn improves environmental performance and reduces the risk of shortage of resources [9]. The global pandemic and on-going global crisis badly hits developing and other emerging countries. This pushes these countries to rethink the linear (take, make, dispose) model to move towards a more sustainable economy which is a circular one. We have lived the linear to extract, produce, consume and discard. Now, circular economy establishes a more sustainable manufacture and utilization model in which raw materials are kept longer in production system so that the same material can be used repeatedly in same or different manner. Circularity is now recognized worldwide as the most capable solution to our planet's frightening sustainability concern. The potential for recycling of scrap is the biggest advantage for steel. Steel scrap has more than 90% recycling rate and it can be recycled infinitely without losing its property. Steel is a fundamental to circular economy. It can be reused, remanufactured and recycled over and over again. In spite of having incredible potential to capture untapped value, there are some challenges in implementing circular economy concept to the fullest in steel industry such as ensuring purity of scrap and maximizing recyclability, level of technologies for separating and removing impurities, lack of integration of supply chain, ease of design to reuse, etc. Therefore, it is time for steel industry to become self sustaining business model which is possible by ensuring circularity of steel [10].

Circular economy is a bold vision with significant challenges. Steel industry must focus on designing new plants or machinery thinking for extended future use. As a key material for a low carbon circular economy, ensuring the competitiveness of steel products is a pivotal task for survival and sustainability of the steel industry. So turning "cold" asset to "gold" assets is a huge benefit of adopting this business model. In theory, to become market leader a business model should focus on cutting expenses, increase the durability of tools and products, lower waste generation and maximize assets. The shift towards circular economy has great potential to expand even by starting small. To reap maximum benefits from circular economy, closed loop materials and energy flow needs to be implemented. This is why steel industry must pay attention for adoption of circular economy to the fullest. As what goes around comes around, so whatever was once old will be new again.

IV. CONCLUSION AND FUTURE SCOPE

Circular economy help address wastage in all these aspects by decoupling growth from resource consumption. By adopting correct circular practices the success of the circular economy can be ensured. Dust and sludge generated in steel industry usually does not return to production system. Their accumulation leads to ecological problems. The process of sintering may be considered for their utilization in the steel plants. This will turn the "cold" asset to "gold" assets for steel industry. There is huge benefit of adopting circular economy business model as steel has more circularity in this competitive market. Most of the integrated steel plants have adopted 4R policy. With use of process mapping, digital technology, the process of circular economy can be utilized more efficiently. Solid wastes generated from steel plant have economic content which must be reused. The shift towards circular economy for steel industry has already begun. Yet, even more innovation is required to ensure full circularity of products in circular economy business model. Policies and regulations as well as digital transformation will accelerate the process. There is no doubt that circular economy business model will provide great opportunity for industries, customers as well as environment.

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