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Examining Energy and Environment Issues in Non-ferrous Metallurgy in the Light of Industrial Metabolism

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Abstract
This paper examines the dissipative nature of non-ferrous metals industry against the idea of industrial metabolism that encompasses, for the sake of sustainable development, values, ideas such as Materials Flow Analysis, Environmental Impact Analysis, Estimation of Environmental Footprint etc. Although the industry is now far away from the dream of 'green' technologies, it is discussed that a beginning has to be made now by analyzing present day processes critically from the iewpoint of materials and energy flow and this should be a mandatory part of Corporate Social Responsibility.

Keywords: Energy, Environment, Non-ferrous, Industrial Ecology, Carrying Capacity, Industrial Metabolism

1. Introduction
India has adequate to abundant reserves of some metals such as Be, Cr, Fe, Mn, Mg, Ti, Zr, Th and the RE's and some reserves also of Al, Cu, Au, C, Pb, V, Zn, Cd, U and Sn. It is imperative that the available resources are to be exploited fully for helping national development. It is important that there is more stress on value addition rather than export of virgin ores. However, as it has been mentioned earlier, metal extraction processes are dissipative and, therefore, the country has to plan for more energy and environment friendly processes for sustainable development. Unfortunately, increasing demands of consumption in today's world has upset the equilibrium and our eco-system can no longer sustain the onslaught on the environment. The water of the holy river Ganges was considered immune to pollution, even to poison, till the middle of the last century and everybody drank the river water as nectar. But now many people, even Sadhus, refuse to take ritual baths during major festivals, so polluted the water has become. The so called 'Ganga Action Plans' have failed to purify the holy Ganga.
Metal productions from ores involve various steps such as ore preparation, beneficiation, extraction by pyro / hydro / electro - metallurgy, melting / refining and then shaping to products of desired cross-section, size, shape etc. All these steps shown schematically in Figure 1, use materials and energy and discharge solid, liquid and gaseous wastes as well as waste heat. In addition, noise, radiation etc. cause further damage to the eco system. Processes are dissipative and there is, therefore need for recirculation of wastes to make them cyclic and approach 'dematerialization' and 'decarburization' i.e. aim at use of less materials and energy on the whole.
Figure 2 depicts schematically how wastes are generated for a specific instance, as for flow of Zn and Cd in production steps for various end uses.
Metal extraction processes are energy intensive, more so when the industry deals with lean ores. Some typical values for different industries given in Table 1 are for base year 2011. These are being reduced globally. The total energy used for steel industry itself is considerable and the same for non-ferrous industry is also considerable when cumulative effect is considered
Processes depend on direct or indirect (i.e. for electricity generation) use of fossil fuels, which implies generation of waste gases that contribute towards global warming. The authors believe that the steel industry alone perhaps contribute around 5%of world's global green house gases while the other metal industries may add 1-2% extra. The amount of wastes generated from non-ferrous industries in India is considerable and cannot be ignored any more. Some estimated figures are shown in Table 2.

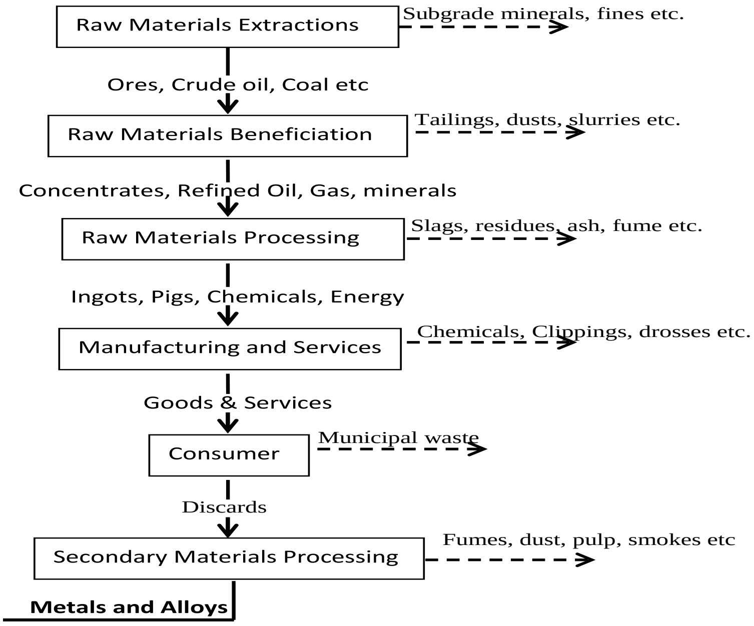

Figure 1: Generation of wastes in metal extraction

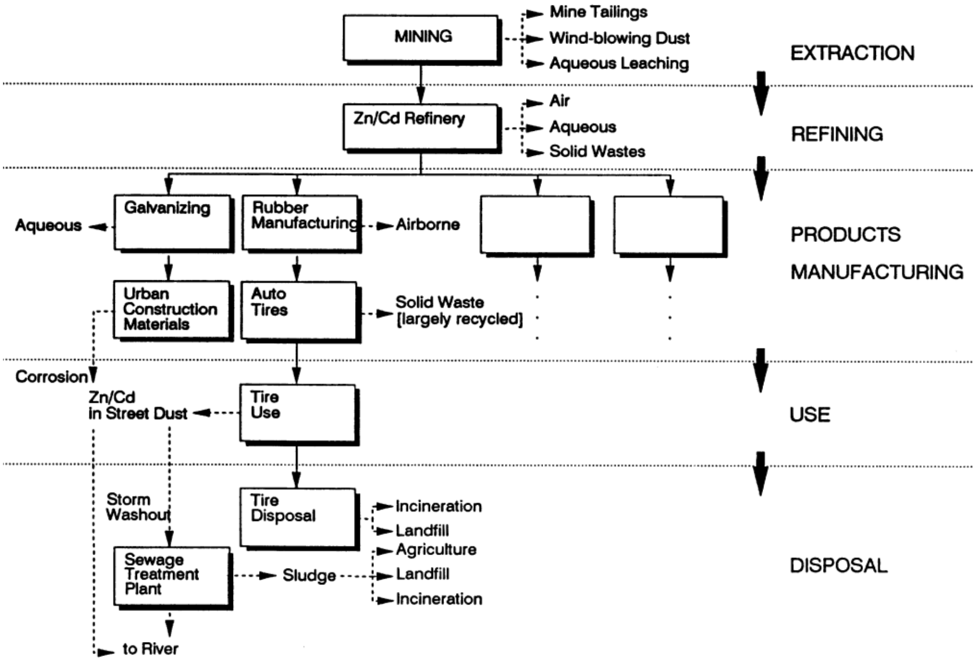

Fig. 2: The flows of zinc and cadmium in different production steps [1]

Table 1: Energy used for world primary metal production

Important metals produced by primary routes	Base: 2011 production in world (Million Metric Tons)*	Rate of energy use in metal production x 10^9 J per year	Form of energy used	Total energy used per year x 10^{15} J	Coal equivalent x 10^9	% World coal equivalent energy used for metal per year
Steel	1,500.00	31.1	Coal/coke	23965	0.802	6.05
Aluminium	44.10	270.0	Elect./coal	5238	0.175	1.32
Copper	16.10	91.1	Coal/elect.	947	0.031	0.24
Zinc	12.40	61.0	Coal/elect.	409	0.013	0.10
Magnesium	0.78	342.0	Coal/elect.	85	0.003	0.02
World	1573.38			30644.5	1.024	7.73

*USGS mineral commodity summary 2012

Table 2: Approximate tonnages of wastes generated by selected non-ferrous industries in India

Metal	Average Feed Grade	Average Conc. Grade	Ore/Metal Production (Mt)	Waste (Tones)
Au	**4.4 ppm**	**-**	**2,700**	**7,45,250**
Al	**-**	**-**	**4,41,00,000**	**Red mud**
Cu	**1.1**	**23.3**	**1,61,00,000**	**33,00,000**
Pb	**2.4**	**62.7**	**45,00,000**	**33,76,186**
Zn	**8.9**	**59.4**	**1,24,00,400**	**22,16,456**

Therefore, with rapid growth of non-ferrous metals production waste management i.e. conversion of wastes into useful byproducts or recycling of the byproducts becomes absolute necessity in order to save both energy and environment. Not only more land is necessary to meet the increasing demand of production, management of byproducts also needs land. In this paper an attempt has been made to highlight the impacts of continual growth of industry on energy and environment related issues.

2. Carrying Capacity

Anthroponogenic and industrial activities always release wastes into our eco-system but nature has an in built system for neutralizing them, e.g. CO_2 is absorbed by plants to produce carbon for their growth and release oxygen. Until the beginning of the industrial revolution in the 17th century and even up to the middle of the last century nature's eco-system had the '*carrying capacity*' to sustain the supporting capacity (Figure 3). Supportive capacity is an indicator to meet the development needs and maintain a quality of life.

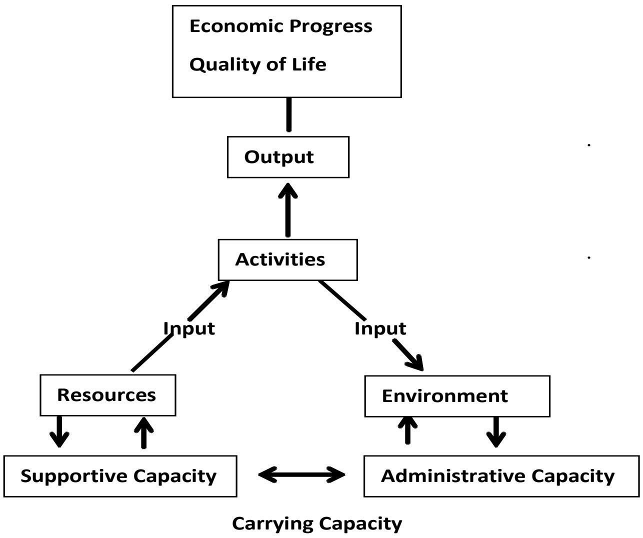

Figure 3: Concept of Regional Carrying Capacity

The waste materials and heat generated by industries have adverse impact on the eco-system in many ways. Industrial activities have various degrees of impact on raw material extractions, air emission, water effluents, solid wastes, energy use, recycling, land use change due to population and agriculture.

Energy is the key issue. There are some basic principles which apply in a wide variety of applications as a guide for rational approach in energy management and this is summarized in Table 3. L, M and H in the table states low, medium and high respectively in the table.

3. Limits of Growth

There has been a great deal of debate on whether our civilization can go on developing as it has done so far. Defining development availability (A) of goods and services, one can write,

A= f_1 (**R**) f_2 (**T**) f (**E**), where

R= Resources

T= Technology, and

E= Ecological support.

The 'Soft' roaders argue that, with time, **A** must decline because **R** is limited and **E** also has a limit. But 'Hard' roaders argue that **R** is not finite and is function of technology and so is **E**. That is, **T** can be continuously developed to ensure unlimited growth of **A**. However, it is becoming increasingly obvious that the pace of growth in technology has not been able to match the depletion of resources and adverse impact on the eco-system. The present energy crisis and global warming are stark examples of this. In fact, many thinkers opine that this century may be the last century of the human civilizations as we know it unless there is an all out effort to save the environment.

Table 3: General principles of Energy Management.

Sl. No.	*Principle*	*Relative cost*	*Relative time to implement*	*Relative Complexity*	*Relative Benefit (% typical)*
1	Review historical energy use	L	1 year	L	5-10
2	Energy audit	L	1 year	L	5-10
3	Housekeeping & maintenance	L	1 year	L	5-15
4	Analysis of energy use	L to M	1-2 year	M to H	10-20
5	More efficient equipment	M to H	years	M to H	10-30
6	More efficient process	M to H	years	M to H	10-30
7	Energy containment	L to M	years	M to H	10-50
8	Substitute materials	L to M	1 year	L	10-20
9	Material economy	L	1-2 year	L to H	10-50
10	Material quality selection	L	1 year	L	5-15
11	Aggregation of energy use	M to H	years	M to H	20-50
12	Cascade of energy use	M to H	years	M to H	20-50
13	Alternative energy sources	M to H	years	M to H	10-30
14	Energy conversion	M to H	years	M to H	10-30
15	Energy storage	M to H	years	M to H	10-30
16	Economic evaluation	L	1 year	L	5-15

Our economic growth generally expressed in terms of growth in Gross Domestic Production (GDP). What, however, is often overlooked is the fact that the so-called development comes at a cost. Some estimates of major environmental costs are indicated in Table 4.

Table 4: Major environmental costs estimated for India [2]

Area	**Impacts on health and/or on production**	**Cost million (US $)**
Urban air pollution	**Urban health**	**1,310**
Water pollution	**Urban & rural health especially diarrheal diseases**	**5,710**
Soil degradation	**Loss of agricultural output**	**1,642**
Rangeland degradation	**Loss of livestock carrying capacity**	**328**
Deforestation	**Loss of sustainable timber supply**	**214**
Tourism	**Decline in tourism revenues**	**213**
Total cost of environmental degradation.		**9,715**
Total costs as % of gross domestic product		**4.53%**

Table 4 therefore clearly shows that developments impacts the environment then there must be remedial majors & these, when considered, modify the GDP values (Figure 4). Thus GDP values need to be normalized to a National Normalized Product (NNP) as indicated in Figure 4.

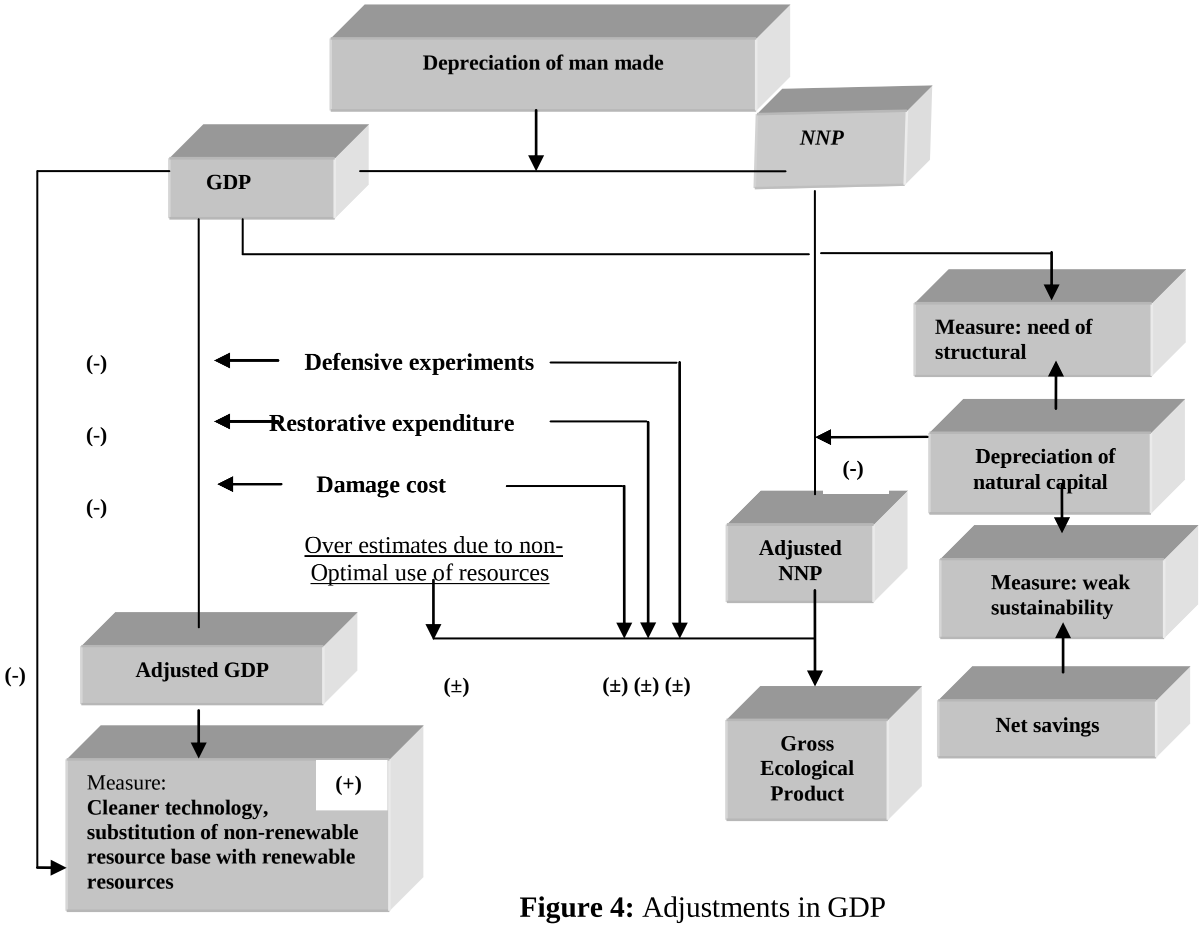

Figure 4: Adjustments in GDP

One estimate [3] claimed that while GDP of India during 1980-90 was showing a growth rate of +5.66%, the GEP or the adjusted growth in GDP accounting for environmental degradation was showing actually a negative growth rate of 4.9w2%. During the period 1991 to 1995 the figures were +4.43 and -4.74 respectively. These calculations do not even include biodiversity losses or depletion of natural resources. So great were the damages done. In today's non-ferrous industries damages have been done by the red mud of the aluminum industry, its effluents and emissions, the fly ash of thermal power plants etc. as well as many dissipative activities.

4. Industrial Ecology (IE)

Industrial Ecology (IE) is the study of material and energy flows through industrial systems, which extract resources from the Earth and transform them into commodities for consumers [4,5]. There is then interplay of technology, economics, sociology, toxicology, natural science etc [6]. If only the conventional process could be changed from the dissipative linear systems to cyclic processes in a loop then the environmental impact will be minimized. In the latter, wastes from one process become inputs for another. These concepts have given rise to the discipline of the *Material Flow Analysis* (MFA) [7], which can be on a natural or regional scale. In MFA one considers the interrelation between the economy and the environment, the first being a sub system of the latter, being dependant on a constant supply of material and energy.

There are only two possible long-term futures for waste materials, recycling and reuse or dissipative loss. The more materials are recycled the less will be the dissipation in the environment and vice versa. Less dissipative loss will imply lesser exploitation virgin sources. Figure 5 shows a scheme for materials recycling.

The U.S. Environmental Protection Agency (EPA) and others have advocated the following strategies.

√ Source reduction
√ Environmentally sound recycling
√ Treatment/ Stabilization
√ Disposal

All these are important aspects; however, planners have to decide based on priorities.

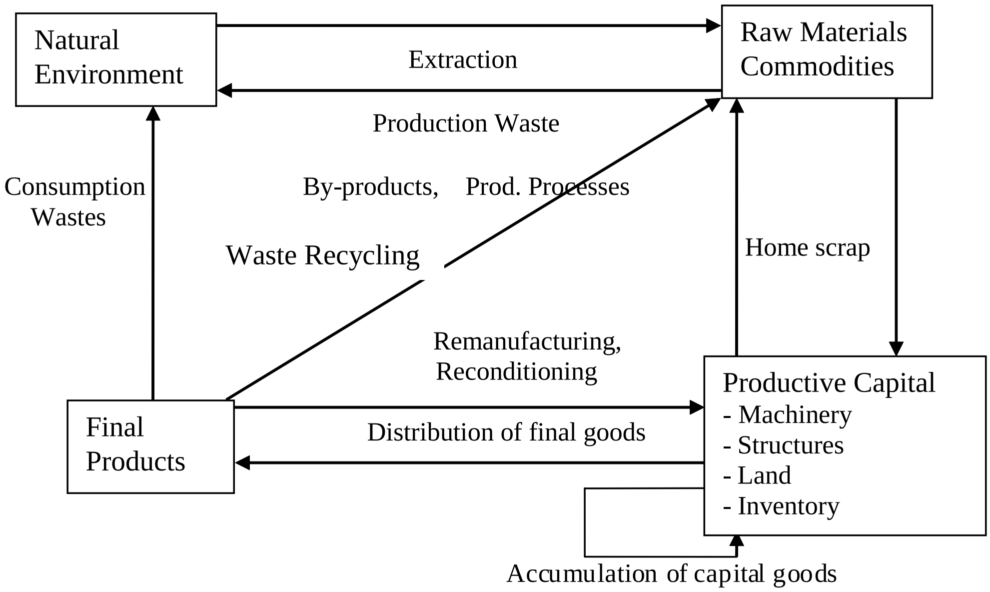

Figure 5: Box scheme for industrial materials cycling [8]

5. Use of Land and Forests

In the May 03, 2012 issue of the Telegraph (Kolkata Edition) there is an article titled 'Fields, forests and markets' by *Jayanta Bandopadhyay* and *Tapas Roy*. In this article the authors have dealt with contradictory demands of development and threat to the livelihood of the ordinary land holders and forest dwellers.

They pointed out that there has been no uniform guideline available for transfer, takeover or appropriation of land in the various parts of the world, where there has been single party rule (China, Vietnam) ad hoc decisions have been forced on the population resulting in large scale relocation of populations. This is not easy in democracy like India. In 1996 the Supreme Court of India apparently observed that even if land were acquired for public purpose 'The Little Indians' should not suffer and there should be adequate compensation. There has been no satisfactory solution of the problem and even the word 'Public Purpose' has not been defined unambiguously. In some public-private partnership deals the public has been misled by the state governments to satisfy the designs of private parties.

There is economic logic of setting up industries on agricultural lands, forests etc. and sometimes there is strong logic to support this, for example, most bauxite deposits are found in forest areas and for exploiting these resources deforestation is necessary and that implies displacement of forest dwellers, there loss of livelihood & traditional life-styles, loss of flora and fauna. 'The cost of this development' is, however, immeasurable. One does not know what just compensation should be and accordingly in India land and forest acquirement is leading to wide spread social unrest and even armed resistance and political turmoil. If democracy and human rights have to co-exist for economic growth and prosperity for all then land use will have to be minimized.

6. Industrial Metabolism (IM)

Some of the Issues discussed so far will now be examined in the light of concepts of Industrial Metabolism [9] (IM) and Ecological Impact (EI). The Greek word '*metabolism'* means to change or transform. In biology it means the sum total of the build up and destruction of cell tissue and the chemical cellular changes that provides the energies for the life process and the elimination of waste materials. Robert. U. Ayres [10] first compared industrial process to biological processes and coined the word Industrial Metabolism (IM).

In biology, physical and chemical processes supply the energy and nutrients for an organism to live and function. It needs input of sun light, chemical energies, food, water, air to produce biomasses, the substance that makes itself and waste products. By analogy an industry also uses raw materials and energy to produce products and wastes. The aggregate of the processes is 'production'. A further transformation of economic goods into services and wastes is also implied by the economic term '*consumption*'. Ayres [10] called the metabolism of the industry as 'the whole integrated collection of physical processes that convert raw materials and energy, plus labour, into finished products and wastes. Materials flow through the society during extraction of raw materials, refining, product manufacturing use and disposal.

There are, of course, some basic differences between biological systems and industrial systems. First, the former can multiply automatically but the latter seldom do that. Second, biological systems are often specialized and cannot change the product from one to another whereas industrial systems are not always so specialized. Third, if we focus attention on the life cycle of individual nutrients in the hydrological cycle, the carbon cycle, the nitrogen cycle etc. we found that IM differs, because the cycles are not so closed since the industries do not recycle materials. However, ideally they should mimic nature.

A cake is produced using intermediate products such as flour, milk, eggs etc., which are derived from primary sources. Similarly iron, ore, coke fluxes etc. along with other materials and energy, produce bulk steel which then leads to steel products. Whenever an industry produces something we need, it also produces something we apparently do not need (e.g. slag in pyro-metallurgy). In natural process, this does not happen and there are only a few 'benign' wastes like coal, oil, natural gas which, because of rampant use in today's world have become main sources of pollution. Today's civilization employs four things to sustain itself, namely human capital (knowledge and skill), previously manufactured capital (equipment, machines, vehicles etc.), natural capital (forms of matter and energy) and social capital (laws, customs of the economy). While these are aimed at producing primary goods there is not enough emphasis on recycling wastes. To aim at cyclic processes we need to understand importance of Ecological Footprint (EF), Environmental Life Cycle Analysis (LCA), Materials Flow Analysis (MFA) etc. Many technologists have thought about industrial materials cycles that will ultimately lead to 'green' processes. Two schemes are shown in Figure 6 and Figure 7 which is self explanatory. Figure 7 is a conceptual Green Steel Plant. It should be noted that cement production as already become an integral part of the blast furnace section as in most plants the slags go for direct quenching for cement production. As regards the other by products indicated, they may become reality in near future.

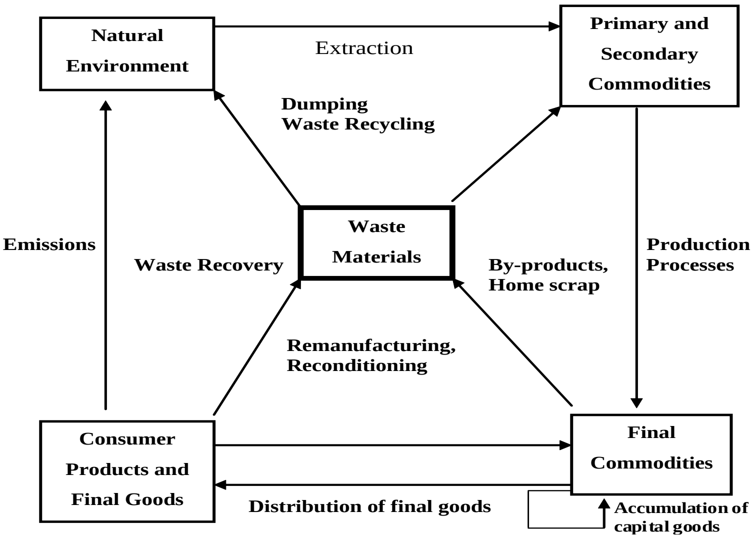

Figure 6: General Scheme for Industrial Materials Cycle

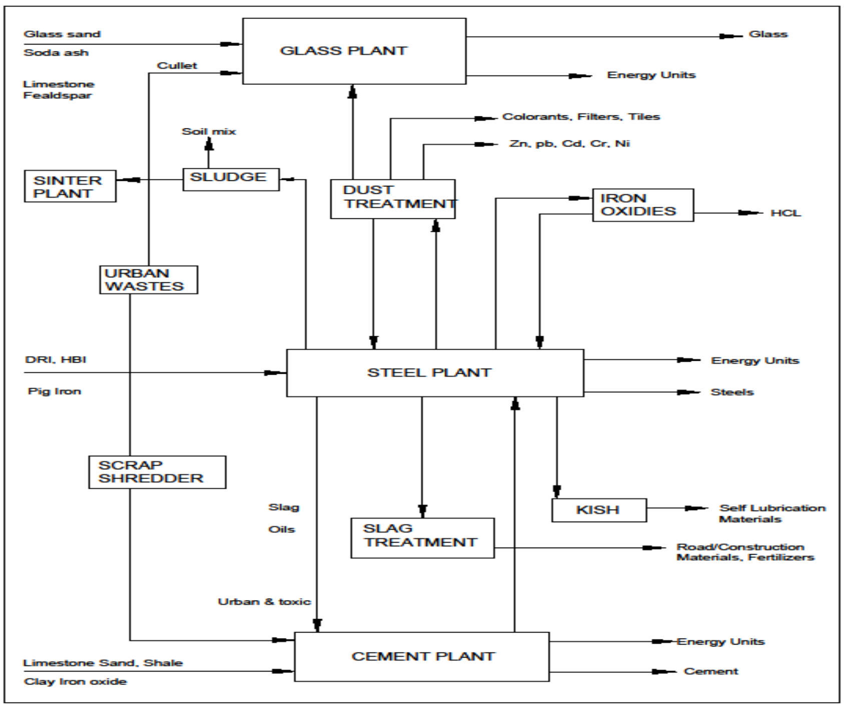

Figure7: Scheme for 'green' Steel [11]

7. Ecological Footprint (EF)

Some workers are now studying environmental impact in terms of ecological footprint (EF) which, for a specified population or economy, can be defined as the area of ecologically productive land (and water body) in various classes of cropland, pasture, forests etc. that would be required in a continued basis to

a. Provide all the energy/ materials resources consumed, and

b. Absorb all the wastes discharged by that population with prevailing technology wherever on earth that land is located.

A method for calculating EF has been given by Rees [12]. The idea is to estimate how large an area of productive land is needed to support the ecological load imposed by a defined population indefinitely wherever that land is located.

Of course, our planet is not so small but even then land is not unlimited. Today the whole of earth does not have sufficient land area to grow plants to take care of the CO_2 released in the atmosphere by our industrial activities. The EF is a physical material and energy flow measure that accounts for the flows of matter and energy to and from specific economy or activity converted into corresponding land and water area needed to support these flows. It can be calculated for a given regional economy, for a nation or for an individual person, similar to the way one calculates carbon footprint.

Today there are newer ways of looking at the environmental impact of products and processes. For example, Life Cycle Analysis (LCA) alerts us to the 'from cradle to grave' approach for environmental impact and resource use of a specific product e.g., newspaper, a car or a plastic bottle. The entire life span of the item is studied and not merely the production processes. Through use and consumption, the life of a produced product and its environmental effects can extend over decades, perhaps even centuries. Many environmental problems occur decades or centuries. Later, because of environmental intervention by societal or economic activity, things that were once ignored are now drawing our attention. For decades some pain killers were routinely given to farm animals. These eventually wiped out vultures that consumed the bodies of dead animals.

8. Basic Footprint Calculations

Ecological Footprint (EF) concept is based on the idea that for every item of material or energy consumption, a certain amount of land in one or more ecosystem categories is required to provide consumption. In our economy today there are innumerable consumer items but, generally, a relatively small number of ecologically significant goods and services represent most of the environmental load imposed by consumption. Only these 'significant' items are used in EF calculation. The "significant" items are: agricultures, transport, housing, industry, service sector etc. The method outlined here refers to resource consumption but the same logic can be applied to many categories of waste production and assimilation.

Step-1: Estimate annual per capita consumption of particular items from aggregate regional or national data by dividing the total consumption by the population size. For this we use national statistical data on production and consumption. The consumption data have to be trade-corrected.

Trade corrected consumption = production + imports – exports

Step-2: Estimate land area appropriated per capital (aa) for the production of each major consumption item i. This is obtained by dividing average annual consumption of the item as calculated earlier (c, in kg / capita) by average annual productivity or yield (p, in kg/ha). Thus,

$aa_i = c / p_i$

Step-3: Compute the total average per capita ecological footprint (ef) by summing all the ecosystem areas appropriated by individual items. Thus,

$$ef = \sum_{i=1}^{i=n} aa_i$$

Step-4: Finally we thus obtain the value (EF) of the study population by multiplying the average per capita footprint by the population size (N)

$$EF = N.\ ef.$$

Rees [12] have done EF calculations so far based on items of five major categories of consumption (food, housing, transportation, consumer goods and services and on six major land-use or ecosystem categories (built up [urban], energy, garden, crop, pasture forest).

Initial EF estimates are based on average national consumption and world average land yields. The standardized procedure yields a preliminary comparison among regions or countries.

9. Ecological Deficits and Global Interdependence

When land area is limited, a region or a country has to depend for its sustainability on imports of ecologically significant goods and services from different sources elsewhere. There is ecological deficit if consumption depends on interval production not backed by sufficient land area. This situation is actually typical of urban-industrial (i.e. high income) regions and even for some entire countries. Many economically advanced countries run an ecological deficit which is often ten times larger than the sustainable natural income that could be generated by ecologically productive land that they own. This is shown in Table-5.

Table-5: The Ecological Deficits of industrialized countries [13]

Country	Ecologically Productive Land (in hectares) a	Population (1955) B	Ecologically Productive Land per Capita (in hectares) c = a/b	National Ecological Deficit per Capita (in hectares) d = footprint – c	National Ecological Deficit per Capita (in % available) e = d/c
Countries with 2-3 ha footprints				Assuming a 2-ha footprint	
Japan	30 417 000	125 000 000	0.24	1.76	730
South Korea	8 716 000	45 000	0.19	1.81	950
Countries with 3-4 ha footprints				assuming a 3-ha footprint	
Austria	6 740 000	7 900 000	0.85	2.15	250
Belgium	1 987 000	10 000 000	0.20	2.80	1 400
Britain	20 360 000	58 000 000	0.35	2.65	760
Denmark	3 270 000	5 200 000	0.62	2.38	380
France	45 385 000	57 800 000	0.78	2.22	280
Germany	27 734 000	81 300 000	0.34	2.66	780
Netherlands	2 300 000	15 500 000	0.15	2.85	1 900
Switzerland	3 073 000	7 000 000	0.44	2.56	580
Countries with 4-5 ha footprints				Aust 4.7 ; Can 4.3 ; US 5.1 ha	
Australia	575 993 000	17 900 000	32.18	- (27.48)	- (590)
Canada	434 477 000	28 500 000	15.24	- (10.94)	- (250)
United States	725 643 000	258 000 000	2.81	- 2.29	- 80

For example, developed countries like Netherlands and Japan that are highly urbanized, densely populated yet relatively resource poor are really not examples of good development models for emulation by the developing world. Japan has a 2.5 ha/capita and Netherlands a 3.3 ha/capita ecological footprint which gives these countries natural footprints about 8 and 15 times larger than their total domestic territories respectively. For a given land area ecological deficit results when the ecological footprint is far too large. Rees [12] argue that there is a marked contrast between the physical and monetary accounts of economic success and this raises difficult developmental questions. Global sustainability cannot be (ecological) deficit-financed. Canada and Australia are among the few developed countries that consume less than their domestic natural income. They have rich resources, low population and much land so that they are yet to exceed their own carrying capacities. Column c in table-5 gives the estimated Figure for available land (ecologically productive) per capita obtained by dividing total land (a) by population (b). This value is largest for Australia (32.18 h) and Canada (15.24 h) value of c (a/b) for Japan is 0.24. Assuming footprint per capita as 2 ha per capita, the National Ecological Deficit per capita is (2 - 0.24) i.e. 1.76. Column e-value is obtained as (1.76/0.24) x 100 as 730. It is seen that most countries listed in the table are running with a deficit, the maximum values being for small countries like Belgium and Netherlands. For Australia, Canada and the U.S, the situation is favourable. They enjoy, per capita, ecological surpluses because of large land areas.

10. The Indian situation

The authors are not aware if such estimations have been done for India. One can easily guess that as there is more development and population growth the country will face more deficits. It should be noted that with a growth not only the population grows in size the individuals also become 'bigger' i.e. the per capital consumption grows. Ecologically productive land, however, does not grow. In recent years there has been much debate on use of agricultural land for industries and there is no simple answer to all the questions raised. Many noted thinkers have argued that not all agricultural land and forests can be left untouched if there has to be development. Yet use of agricultural land and

forests has become a serious political and emotive issue. The proper answer can only be found if India is able to formulate a model for development that suits its unique needs. One need not follow the path taken by the developed countries which in the past managed to get access to productive land beyond their boundaries for their industrial development.
If industrial processes are suitably integrated so as to mimic the recycled loops in nature then avoidance of dissipative activities will reduce waste generation. There will be overall reduction in virgin materials in production or, in other words, dematerialization. The ecological footprint of the industry will be, accordingly reduced. For sustainable development the other obvious option will be to limit consumption to sustainable levels by avoiding wasteful life style and excessive wasteful consumption. The US has a considerably higher EF (ha/person) than many developing countries such as India. Small EF values are generally linked to poverty.

11. Corporate Social Responsibility

Non-ferrous metallurgy remains at present in a primitive stage as regards the ideal state of a cyclic process that mimic recycling in nature. Therefore, it is necessary that the industry be more sensitive to the basic ideas of Materials Flow Analysis (MFA), Ecological Impact (EI), Ecological Footprint (EF), Life Cycle Assessment (LCA) etc. that are all part of 'Industrial Metabolism'. These now have to come within the ambit of Corporate Social Responsibility (CSR) whereby every industry will take responsibility of not only damages it does to the environment but also take more than just remedial measures to fight environmental degradation.
There have been scattered attempts at waste recycling - e.g. utilization of red mud and/or fly ash in producing building materials, road construction etc. treatment of various wastes to produce value added products, alam from Bayer leach liquor, useable carbon from spent cathodes, Zinc from Zinc dross , nickel from nickel overburden etc. However, there should be far greater thrust towards waste recycling.
Reduction of energy and waste generation needs to be given high priority and for this, elaborate bench marks need to be established. The ultimate goal should be to approach green technologies as envisaged in Industrial Metabolism.

Conclusions

It is well accepted that non-ferrous metallurgy comprises dissipative processes far from ideas of '*green technologies'* that envision zero waste. Yet, a beginning needs to be made and for this one has to start with materials flow analysis and energy audit with an idea to '*dematerialize*' and '*decarbonise*'. It should be imperative for the industries to try to transform the present day dissipative processes towards processes in a waste free loop through their programs under Corporate Social Responsibility.

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