In the three earlier NMD addresses during 2001 to 2003, respective Presidents of IIM shared with us their concerns over various problems and challenges faced by the metallurgical fraternity covering broadly from metal specific approach to metallurgical education to drivers for the metal industry. While highlighting the various issues ranging from depleting resources to novel and innovative materials, all of them touched upon two common subjects of availability of energy and its optimum utilization through recycling of waste which plays very important role in the sustainable development as applicable to many industries drawing world wide attention in various forums. For this year’s Presidential address I have decided to start the talk with energy generation issue and then proceed to focus on conservation of energy, environment, metals and materials through processing of various secondary resources by metallurgical industries.

In any metallurgical industry related with production and processing of metals, availability of energy at low cost and sustainable manner as well as its optimum utilization is of prime importance. Among the five commercial modes of power production namely thermal, hydel, solar, wind and nuclear, the largest share is that of thermal. Unfortunately thermal power plants based on burning of coal available as fossil fuel is non-sustainable in nature and leads to production of enormous amount of Green House Gases (GHG) like CO₂ that cause global warming. In this context hydel, solar and wind power stations are pollution free and sustainable in nature notwithstanding their inherent specific limitations. For example renewable energy sources like solar and biogas are expensive and yet to demonstrate their ability to satiate the growing demand of the industrial and commercial world. Nuclear power generated by countries with access to natural and enriched uranium as fuel is also not sustainable in the way it is practiced presently. But such power generation as conceived in our country with limited and large reserves of uranium and thorium respectively by Dr. Homi Bhabha- founder father of our nuclear energy programme is uniquely sustainable in nature.

In this three stage nuclear power programme of our country actively pursued by Department of Atomic Energy, available natural uranium is being used as fuel in the first stage pressurized heavy water reactors and can generate 10 GWe of power for 40 years and in the process generate enough depleted uranium and plutonium to act as fuel in the second stage fast breeder reactor with Th-232 as blanket making available 500 GWe of power for 100 years. These second generation reactors are expected to convert Th-232 to U-233 for acting as fuel in the third stage thorium breeder reactors with Th-232 as blanket to breed U-233 for its recycle. These third stage breeders are destined to generate 500 Mwe power for 350 years. India has presently reached the second stage with taking on the construction of the first 500 Mwe Prototype Fast Breeder Reactor (PFBR) which is expected to be commissioned in the year 2010. DAE has the confidence that energy security for India in the next few decades would be realized through fast breeder reactors.

Possibly the cleanest mode of energy generation is by burning of hydrogen in analogy to carbon as the per unit weight of the former can generate about three times the calorific value than the later. The success of hydrogen as fuel would however depend upon its availability as by-product from electro chemical and petrochemical industries amongst any other, or its generation through photo catalytic reaction mimicking the nature as in the case of growth of plants, its storage through metal hydride system and final recombination reaction with oxygen by using fuel cell concept. Alternatively such hydrogen is allowed to react with GHG like CO₂ to generate methanol as a replacement for gasoline to be used by Proton Exchange Membrane (PEM) fuel cell. DAE is also actively pursuing a programme on production of hydrogen by thermolysis of steam by utilizing the heat generated in nuclear reactors. Till such futuristic approach and
R&D efforts, become a commercial reality, hydrogen may remain as the elusive fuel in spite of its enormous resource availability in the mother earth.

As the world marches towards generation and use of sustainable green power, through stringent emission norms as applicable by market mechanism such as carbon trading, energy is likely to become costlier in years to come. It is therefore, imperative that in making, shaping and treating of metals, alloys and materials all out efforts should be made by metallurgical industries to reduce emission of GHG and conserve the energy input and material output. It is in this context, recovery of metal values from all secondary resources assume great importance.

Unlike primary resources, which are metal, bearing ore bodies, secondary resources are generated in large volume or tonnages during the process of extraction, refining, consolidation and fabrication of primary metals or by other non-metallurgical industrial operations. For example, production of 1 million ton of hot iron metal generates approximately 0.36 million ton of slag along with 0.4 billion NM² of hot flue gas. Similarly for recovery of every million ton aluminium and zinc one has to dispose off about 3.5 and 0.83 million ton of red mud and jarosite as residue respectively. Depending on the nature of such resources, it may not be always possible to economically recover the desired metal values but effort should be made to convert them to useful materials. The term secondary resources encompasses a whole range of materials and can be categorized depending on their physical state (solid/liquid/gas) or originating process (pyro/hydro/electro metallurgical operations) or originating industries including many belonging to non-metallurgical sectors like automobiles, petrochemical, fertilizer and nuclear to name a few, who in turn generate obsolete metal scrap after the metal bearing products have out lived their useful lives. Since metal scraps are already in liberated form- at worst contaminated with metallic and or interstitial impurities or unwanted non-metallic materials, its recycle after proper cleaning and sorting leads to considerable energy savings. In the transport category, discarded automobiles happen to be an important source for scrap metals including ferrous and non-ferrous. As per a decade old data, each year about 11 million ton of metals were recovered in USA from about 10 million discarded automobiles. It is also reported that in the western world more than 90% of metal scrap generated are ferrous in nature and since its value is low, large scale economical handling is required to achieve recycle rate of the order of 35%. Recycle of each ton of iron scrap results in reduction of 4 ton of primary production waste. Steel scraps along with sponge iron happen to be the exclusive input to electric arc furnace (EAF) of steel making. In comparison to recycle of steel scraps those of non-ferrous metals like zinc, aluminium, copper and lead are of the order of 20, 40, 45 and 68% respectively. There is much talk about the need of increasing the share of aluminium recycle. It is said that by the middle of the century, India would require around 2.34 million ton as per the projected higher per capita consumption.Assuming that the production capacity of primary aluminium metal will reach a figure of 1.5 million ton per year, the balance 0.84 ton has to be produced through recycle. According to experts aluminium could be recycled as many times as possible and during recycle and each re-use would lead to 95% savings in energy since the energy required to extract every kg of aluminium from bauxite is 37 times that required to melt 1 kg of aluminium scrap. Large sized reverberatory furnaces are used for re-melting aluminium scrap at a rate of about 7 ton per hour. During re-melting proper procedure has to be followed to minimize surface oxidation of the aluminium melt. In our country, there is no systematic development of aluminium recycle. Indian Aluminium Company (INNALCO) happens to be the only plant in the country to have a scrap recycling plant at Taloja near Mumbai.

In the case of copper, against a primary production figure of 0.3 million ton in our country, almost 0.1 million ton of secondary copper is produced through processing of scraps generated by Electricity Boards, Railways, Defense sectors and those sourced through imports. In contrast to aluminium and copper, recovery of zinc metal from zinc scrap is minimal as it is
predominantly used on steel for protection purpose called galvanizing. In fact large amount of zinc is lost every year as fumes during reprocessing of galvanized scrap. Most of the zinc is recycled as chemicals like zinc oxide and zinc sulphate or pure zinc dust by processing of various secondary resources like iron-zinc intermetallic compound, oxide ash, and dust rejected by galvanizing bath. In India, production capacity of secondary zinc metal and its sulphate are estimated to be 50,000 and 100,000 ton respectively. A whole range of base metals like nickel and copper as well as refractory metals such as niobium, tantalum, vanadium, molybdenum and tungsten report in varieties of scraps like waste hard metal tool bits, grinding wastes, rejects from lamp industries etc. Although many promising techniques have been developed on laboratory scale to recover such metals, the practice of large scale processing of refractory metal scraps are limited.

SLAGS

Slag – a part and parcel of any pyrometallurgical operation is essentially considered as a waste as it is deliberately formed with or without incorporating suitable flux to make the resulting metal or matte phase free of undesirable components present in the ore body. The slag may or may not contain some residual metal values of interest. The sole exception is possibly titania slag produced by electric arc smelting of ilmenite in which slag acts as a value added material for its conversion to sulphate or chloride grade TiO₂ pigment. Hence in most of the cases slag has to be suitably disposed of with due concern to the environment. Between ferrous and non ferrous industries, the share of the former in slag generation is much higher and any typical blast furnace slag is composed of silica, alumina and calcium oxide. Such a material after suitable treatment has found excellent application in the production of Portland slag cement - a commodity consumed in large quantities by any country. For such specific application the slag after tapping has to be quenched for formation of glassy structure and granulated. A cement plant with capacity to produce 0.1 million ton per annum can consume 30,000 ton of granulated slag. In USA, more than dozen plants together are producing 2 million ton of ground granulated slag for its use by the cement industries. Use of such slag not only leads to better quality cement with superior properties but also reduces CO₂ emission by cement plants significantly. For example in USA, all the cement plants together release 80 million ton of CO₂ every year due to decarbonation of limestone. Substitution of granulated slag can result in 0.5 ton reduction in CO₂ emission for every ton of cement produced. The non ferrous slags of copper, nickel, lead and zinc are generated during the processing of their respective sulphide concentrates using various combination of unit operation like roasting, smelting and converting. In USA, the non-ferrous metal industries produce about 4.5 to 5 million ton of copper, nickel, lead and zinc slags. Copper and nickel slags have been used as granular base and embankment materials, aggregate substitutes in hot mix asphalt, back fill of railway ballast, grit blast abrasives and roofing granular materials. The copper converter slag in our country is known to contain significant concentrations of nickel and cobalt warranting their recoveries.

FLY ASH/FLUE DUSTS

I like to cover in this section two waste materials generated in large quantities the first being fly ash as a result of combustion of coal primarily by thermal power stations and the other is flue dust released by iron and steel industries. In the year 2002, India generated 0.105 million megawatt of total electricity out of which thermal power stations contributed about 70% - in the process contaminated the atmosphere with 100 million ton of fly ash which is essentially composed of unburnt carbon, iron oxide spheres, cenospheres and aluminosilicates with mean particle size of 10 to 20 micron.

Such coal-ash pollutes the air as well as water too and requires a huge land area for its disposal the value of which cannot be compensated by money specially for a country like India, where land population ratio is much less as compared to other countries. In the presence of coal ash when obnoxious gases like SO₂, NOx and hydrocarbons are released into the environment, synergistic chemical reactions take place degenerating the thriving of flora and fauna in the adjoining region. Fly ash can be used for making a variety of building products like bricks, concrete, block, light weight aggregate, flyash polymers composites, roofing sheets etc. Although the present scope of the utilisation of flyash is non metallurgical in nature, if it happens to contain some heavy metals like vanadium depending on the nature of coal they can be recovered by adopting suitable extraction scheme.

Generation of significant quantities of flue dust during operation of the blast furnace and its dumping in the plant premises causes environmental and space problem. Flue dust recovered after wet cleaning of the flue gas are sticky and tend to agglomerate after long exposure. It typically contains high values of iron
oxide and carbon along with silica, alumina and calcia as well as harmful elements like Na, K, Zn and Pb. The carbon and iron value from such material should be recovered for recycling by proper physical beneficiation process like flotation and magnetic separation respectively. Its recycle in the sinter plant should be feasible only after effective separation of the alkalis.

**RESIDUES**

During the hydrometallurgical processing of non ferrous metal ores and concentrates, wastes are generated in the form of residues and disposed off as they have low enough concentration of primary metals. These residues are called mud, sludge, precipitate etc depending upon their points of origin and characteristics. Let us consider few such materials as possible secondary resources. During refining of bauxite ore to pure alumina by Bayer’s process two prominent residues are generated – the first is popularly known as red mud on account of its colour. It is essentially the left over in the form of slurry with 25% pulp density after the alumina value is extracted from bauxite by digestion with caustic and it is typically composed of 30% Fe₂O₃, 19% Al₂O₃, 14% TiO₂ besides about 38% SiO₂ + CaO + Na₂O. A look at the composition of red mud suggests that one can possibly recover the iron, aluminium and titanium values from such material. One possible method is to reduce this material to ferro-titanium as has been tried by NALCO. Attempts have also been made to use this as flocculants, bricks for buildings and as filler in pigment. But fact is that no commercial process is operative to take care of such a material generated in huge quantities and the present disposal method consists of further dewatering by the use of high efficiency thickeners and placing at impoundment area lined with impervious clay in engineered and managed stacks. In this respect vanadium bearing sludge produced during purification of Bayer’s liquor has been put to good use in the recovery of pure salts of vanadium or for production of ferrovanadium. Like red mud in aluminium industry production of large quantity of jarosite as a residue is another vexing problem faced by producers of zinc metal. Based on its composition jarosite can be called ferric-sodium/ammonium sulphate which is precipitated from the leach liquor generated after acid leach of the calcined zinc ore to eliminate soluble iron. Such material is voluminous in nature and may be associated with heavy metals in low concentrations. It is required to be thoroughly washed before dumping in the pond. Hydrothermal treatment of this material to hematite product of much higher density is a good possibility because it can raise the life expectancy of storage pond significantly or can be considered for production of cement and iron.

Electrolytic operation practiced by metal industry for the purpose of winning, refining and plating or coating generate residues like slimes containing two types of materials namely intermetallic compounds of Cu, Se, Te and Ag having no solubility in the electrolyte and precious metals like Pt, Au, and Ag. The anode slime has to be removed periodically for the recovery of metal values. Similarly during electroplating and electro machining operations, metal bearing hydroxide sludge is generated. Recovery of metal values particularly the precious ones from such slime, or sludges by suitable hydrometallurgical processing offers economic benefit and lesser environmental threat.

**SPENT BATTERIES**

Between two major categories of batteries namely wet and dry cell the former are lead-acid variety primarily used for automotive products. A typical lead acid battery weighing 16.4 kg contains 10 kg of lead with more than 50% as sulphate and oxide paste remaining as antimonial lead containing 3 to 11% Sb. In fact 75% of total demand of lead in the world is due to this particular use in the manufacture of lead acid batteries. When such batteries are discarded it can be processed to recover the lead value. In fact in our country there are 6 producers of secondary lead in the organized sector with a capacity of 45,000 ton per annum indicating a recycle rate of 40%.

The other major category of batteries is dry cell type also known as consumer batteries – primary and rechargeable. While primary batteries are discarded on regular basis when spent, the rechargeable batteries are repeatedly used prior to final discard. All these batteries - alkaline manganese, zinc-carbon, mercuric oxide, silver oxide, zinc-air, nickel-cadmium, lithium ion, nickel metal hydride carry host of non ferrous metals – some of them valuable and some toxic demanding their safe disposal or more preferably recycle. About a decade back as many as 4 billion dry cell batteries weighing 0.146 million ton were sold in the domestic market of USA. Today these numbers will be staggeringly high considering the phenomenal growth of portable computers, cellular phones, which are major user industries for rechargeable batteries. Although such statistics on volume of spent dry batteries generated in our country and it’s processing is possibly not available, its role on sustainable development cannot be neglected.

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SPENT CATALYSTS

Use of catalysts based on some base, refractory and noble metals is a common practice in chemical, fertilizer, petrochemical and refining industries carrying out production of acid and ammonia, as well as operations like waste hydroprocessing, high temperature shift, hydrogenation etc. These catalysts while on use become ineffective over a period of time and are required to be regenerated or replaced. Spent catalysts therefore emerge as one of the important secondary resources of certain metals like Cu, Ni, Co, Zn, Cr, V,Mo and W as well as precious metals like Ag,Pt and Pd. As per a published conservative estimate, in the early eightees 12,000 ton per year of non noble critical metals with nickel enjoying a share 52% were discharged in spent catalysts in USA alone and less than half of this amount was recycled. A large number of processes are patented as well as reported in literature to recover the metal values from different spent catalysts using both pyro and hydro metallurgical techniques. Adequate precautions are required to be taken in handling and processing of spent catalysts as some of them are known to be pyrophoric in nature and can pose health problem.

CONCLUSION

Conventional metallurgical industries like others are based on the holy trinity of production ,sales and profit with the stress on maximizing the bottom line . The current trend stressing on the sustainable development is demanding an additional bottom line in terms of conservation of ecology and environment. This can be achieved through appropriate legislation reflecting the will of government and the society at large, commitment of producing industries and adoption of appropriate technology leading to conservation of energy and mineral resources. It is in this context that I have tried to drive home the message to this august gathering the importance of exploiting the secondary resources by the metallurgical industries.