Issue 5 volume 7, Nov. –Dec. 2015
ISSN 2249-9954

Techno-economic Feasibility of Recycling E-waste to Recover Precious Metals

T. A. Patil[1] and Sanjeev T. Patil[2]

[1]Tata Chemicals Ltd., Mumbai-400 059, India. Email :tapatil@rediffmail.com;

[2] Metallurgical and Materials Engineering; Visvesvaraya National Institute of Technology Nagpur-440010. Sanjeevpatil29@yahoo.com

Abstract :

Ewaste is techno-economic- socio-environmental issue on global scale and is difficult to manage in less developed countries. On one hand its precious metals content recovery and plastics cables pose splendid business opportunity in terms of employment and national economy; on the other hand, toxic elements and gases pose environmental threat. The experimental results from recycling simulated ewaste shows recycling ewaste techno-economically feasible at all levels implying very profitable business in small, medium scale and large sectors. The aqua regia route is user-friendly and environmentally safe. The recycling of ewaste printed circuit boards (PCB) looks promising business case with IRR = 47% and pay back of around 2 years. It contributes to clean environment, job opportunity, national economy following best practices of safety, health, environment by organized sectors backed by government regulations.

Introduction :

The "ewaste" is electrical or electronic device with no further economic value to the owner. When the devices become useless for current owner can still have value to next users to sell or reuse, recovery. Ewaste is enough complex by techno-economic-socio-environmental controversial issue posing both risks and opportunities. The recycling ewaste is clearly advantageous from an environmental perspective. The environmental impacts of ewaste recycling is compared to base line reference of incineration of all ewaste and primary production of raw materials. The ewaste recycling is a lucrative business.

Ewaste contains dozens of substances, toxic metals such as lead, mercury, arsenic, cadmium, selenium, hexavalent chromium and flame retardants in printed circuit boards. Considerable environmental damages are caused as a consequence of precious metals recovery from ewaste. For example, to recover gold from ewaste, wet chemical leaching processes use hazardous substances cyanide and nitric acid. Scientific data base about these processes are scarce.

 Issue 5 volume 7, Nov. –Dec. 2015
ISSN 2249-9954

From material balance on PCB recycling, the recovery of only about 50% of available gold as shown by unorganized sector is just unacceptable. The economic profit can be much higher if material is sold to industrial smelter. The emissions to environment decrease drastically if the waste is treated with the metallurgical technique. Lack of regulation, e-waste disposal in uncontrolled manner, inappropriate recovery methods are the nagging problems in the developing countries owing to socio-economic issues, safety, health and environment concerns.

In India ~400,000 Tons ewaste was generated in 2009 of which just 19,000 Tons was recycled in 100,000 Tons processing capacity then existed. About 800,000 Ton e-waste was generated in 2012. The

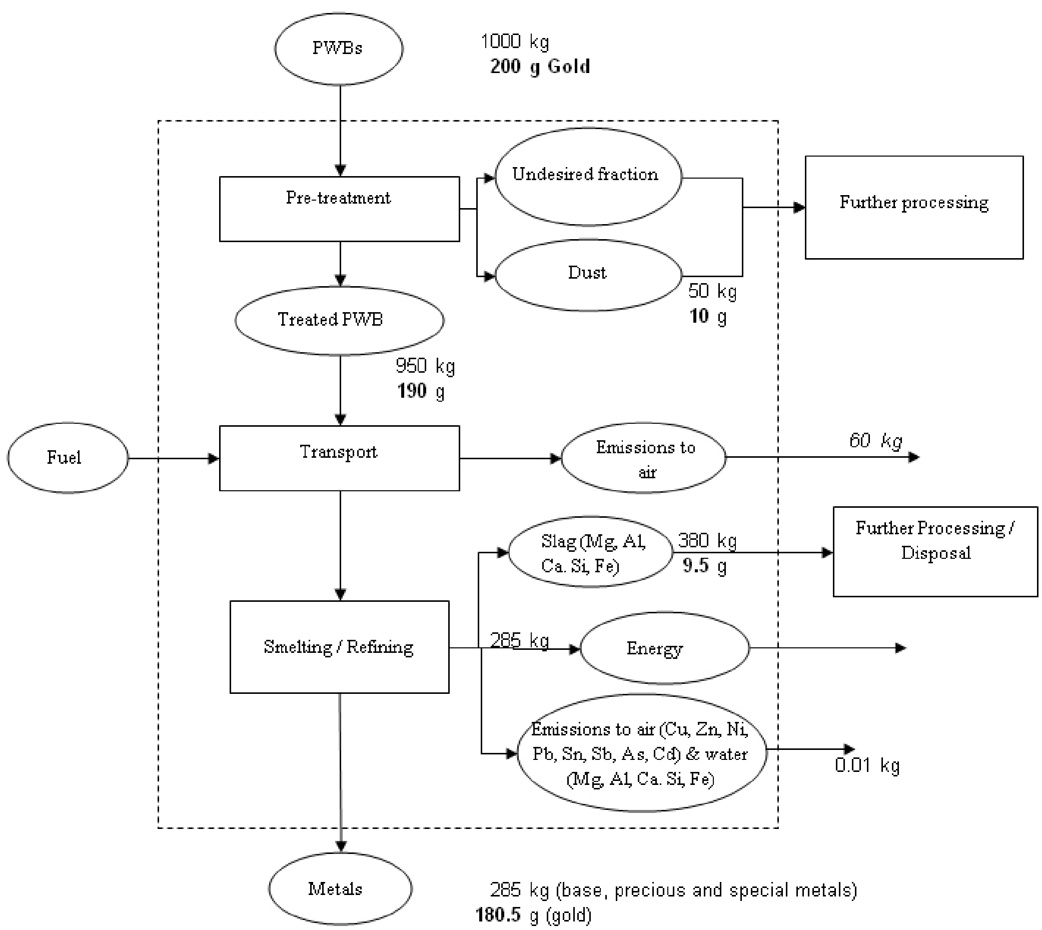

Figure 1 : Material flows of PCBs in the smelting / refining scenario formal sector (Rochat).

informal recyclers exploit child labour. A 50% gold loss during segregation is depicted here, recovery efficiency is ~25% max. & profit $ 700/Ton. Where as the organized sector smelting/refining achieves >95% recovery, profit 3800 Euros/Ton. Significant loss is during shredding. This study emphasizes on gold recovery process for recycling simulated ewaste; material and energy balance to evaluate gold

 Issue 5 volume 7, Nov. –Dec. 2015
ISSN 2249-9954

recovery process. The processes conducted are qualitatively evaluated based on such environmental impact caused.

Socio-economic assessment and feasibility study on sustainable e-waste management :

Monthly incomes of ewaste collectors range $ 70 -140, for refurbishers $ 190 -250 and recyclers $ 175 - 285 is commonly scene in many of the Asian and African countries. Most of the poor workers of informal e-waste recycling sector face chronic food insecurity and still prefer to this informal sector as they get regular rapid cash flow income which is absent in agriculture-driven households. It is very pathetic scene in less developed Asia and African countries. The children earn less than $ 20/month. The child labour deprives school and play time of these poor children. Most employed in e-waste recycling are in the age bracket 14- 40 years, work 10-12 hours/day.

Table 1. : Estimated e-waste generation from household in a year

Quantity	TV sets	Desktop PC	Laptop PC	Mobiles	Refrigerators	Washing Machines	Total TPY
Tons/Year	106,324	24,816	7,845	4,537	88,381	53,539	285,441
Units/yr	3,544,130	992,623	1,569,092	45,369,624	1,964,019	1,338,466	

CRT – Cathode Ray Tubes

Cost-analysis model accounts expenses involved in e-waste personal computer (PC) dismantling & sorting facility for 139,000 TPY (desktop PC + portable PC) carried out on monthly basis business revenue $10.41 million/month (Rs. 72 cr/year). Refurbishment process neglected in this analysis could bring additional revenue for the business. Total expenses for this activity was about $ 9.3 million and benefit was $ 1.13 million (or Rs. 7 cr) /month, depending on metal content and prices.

Table 2 : Summary of cost and benefit analysis (1 $ = Rs 62 taken at the time of calculation)

Cost	Rs. Crore	% contribution	USD
Collection	40.635	72.44	6,725,611
Dismantling and sorting	11.396	20.46	1,899,363
End processing cost	03.911	07.06	655,270
Transporting PWB to smelting location	00.216	00.04	3,600
Transporting waste for incineration/burial	00.036	00.001	60
Total costs	55.703	100.001	9,283,905

Revenue from	Rs. Crore	% contribution	USD
Copper	15.539	24.88	2,589,468
Aluminum	03.598	05.76	599,698
Iron	08.794	14.08	1,465,725
PCB high grade	29.069	46.54	4,844,767
PCB medium grade	05.444	08.72	907,282
PCB low grade	00.016	00.03	2,626
Total Revenue	62.457	100.00	10,409,567
Benefit	**06.754**		**1,125,662**

The material cost constituted ~ 37% of total operating cost that includes cost to outsource the recycling of CRTs ~ $ 0.33/kg; labour cost ~ 28% of total cost without accounting for overhead. Other cost drivers are transportation, building and equipment costs. The CRT glass recycling and sorting, collecting, dismantling seems to be costliest and most labour intensive operation. The largest revenue sources are the fee charged to customer, and metal recovery. A typical set up of 20 employees treats 2500 - 5000 TPY heterogeneous e-waste in developing country.

Process comprises unit operations viz. collection, transportation, sorting, dismantling, size reduction, separation, recycling, sale. The costs involve labour, energy, material, transportation, equipment, building. The base line costs are calculated and key process parameters evaluated.

Unit operation cost = material + energy + labour + transportation + equipment + building (1)

Total cost = Summation of cost of each unit operation (2)

Revenue = Resale system/components + recovered materials + fees to customers (3)

Table 3 A : The annual operating cost for 2500 TPY e-waste MRF (CRT = 75%wt & CPU=25%wt)

Labour	Energy	Material	Transport	Equipment	Building	Total
28%	02%	36%	14%	08%	12%	100
$ 41720	$ 2980	$ 55130	$ 20860	$ 11920	$ 17880	$ 1490

Table 3 B : The annual operating cost for 2500 TPY e-waste MRF (CRT = 75%wt & CPU=25%wt)

Collection	Sorting	Testing	Dismantling	Size reduction	Separation	Landfill	CRT Recycling	Sales	Total
12%	14%	04%	12%	04%	11%	05%	30%	08%	100%
$ 17280	$18720	$ 5768	$ 17280	$ 5768	$ 14400	$ 7210	$ 43200	$11536	$ 144000

Precious metal recovery from e-waste is one of the most profitable business in recycling industry. The ewaste treatment operations above 2500 Tons/year, show profitability.

 Issue 5 volume 7, Nov. –Dec. 2015
ISSN 2249-9954

Table 4 : Chemical composition of typical waste PCB sample

Materials	Sample 1* %w/w	Sample 2** % w/w	Literature data (3)
Cu	27.99	25.24	20
Al	00.47	00.69	2
Pb	02.17	02.22	2
Zn	02.01	02.05	1
Ni	01.23	00.93	2
Fe	01.18	00.98	8
Sn	03.26	03.17	4
Ceramics,	20.41	22.14	30% max
Plastics	32.07	32.41	30% max
Au,	440 ppm	890 ppm	1000 ppm
Pt,	57 ppm	17 ppm	-
Ag,	1490 ppm	1907 ppm	2000 ppm
Pd,	50 ppm	47 ppm	50 ppm

This study tries to evaluate gold recovery process qualitatively by recycling PCB ewaste applying material and energy balance to assess environmental impact caused by such processes. The best available technologies for recycling scrap jewelry/waste desktop computers involves collection from households and business premises to dismantle, sorting pre-processing parts in desktop computers and forward to refiners to recover efficiently at high quality environmental standards.

The European consumers hand over their e-waste and pay for proper sorting of devices to transport to collection point. In the developing countries, e-waste collection is organized in an informal door-to-door collection where collectors pay money to pickup e-waste. These collection systems are said to be more efficient than centralized collection.

Pre-processing includes shredding, crushing & mechanical sorting to manual operations achieve benefits of perfect output fractions. Sorting uses density, magnetism, electric conductivity, particle size etc. Precious metals loss are ~ 20%–58%. Manual pre-processing minimizes losses in refinery processes.

In socio-economic lower wage countries, manual dismantling, sorting, pre-treatment is preferred environmentally and economically as it requires low cost simple tools by unskilled personnel for steel & aluminum, plastics, screws, precious metals from PCBs . With thin cables, it is quite difficult to liberate all copper. Manual stripping is very labour intensive. Automatic shredder and sorting machinery is capital intensive. An investment of $ 25,000-100,000 depending on size and capacity is envisaged here. Machinery needs electricity 400V/ 50Hz /3phase-100 kW power .

The output fractions of manual pre-treatment in end-processing combine efficient material recovery with high environmental standards. Steel scrap is processed in electric arc furnaces to form steel products. The aluminum scrap is passed on to remelters to produce cast alloys. Precious metals fraction are sold to end-processing units pyro-metallurgical and hydrometallurgical refineries. Pyro-metallurgical refining is preferred to hydrometallurgical refining as melting process affects input materials all through, while hydrometallurgical treatment affects surface layer of feed material. The hydrometallurgical refineries provide a low cost solution for emerging economies, and are yet to publish comprehensive flow sheets

Issue 5 volume 7, Nov. –Dec. 2015
ISSN 2249-9954

using strong acids or caustic with considerable risks for human / environmental health. The copper is sold to secondary copper refiners.

Experimental :

A pilot scale study treating jewelry plant shop floor dust and plant effluent sludge, ewaste, casting powder recycling on semi-commercial scale unit with 8-10 ppm gold was subjected to panning, gravity separation, hydro-cyclone, smelting operations followed by environmentally benign aqua regia route. The sample analysis for precious metals and base metals was done on ICP-OES (Perkin-Elmer Plasma 400) equipped with spectral range of 160-800 nm covered by two gratings.

Results and Discussion :

Ewaste Recycling scene in Bangalore city in India depicts generation of ~ 8000 Tons computer waste/year. In one informal recycling unit situated on a roof approx. 50 m^2 deals with scrap, dismantling equipment to recover precious metals. Furnace and materials are stored in a room 20 m^2 on roof. The acid containers are outside. This facility has 3 workers of 10 - 20 years age, to recycle 1800 kg waste /year, for 7.2 kg gold production. If the gold concentration in input material is low, cyanide leaching is used. If the input material is high-grade material, mercury amalgamation as detailed below.

Table 5 **:** Input/output materials of the cyanide leaching gram per gram recovered gold

Input	g/g gold recovered	Output	g/g gold recovered	Destination
Input material	20700	Body components	20700	Solid waste stream
Water	53600	Water vapour	8410	Air
		Water solution	30200	Drain
		Silver solutions	16800	Recovery
Substance 1 (containing cyanide)	185			
Aluminum	46.7			
Nitric acid	677	Fumes (NO_2)	80	air
Lime	46.7			
Silver	117	Silver	6.67	Process cycle
		Silver solutions		
		Gold	1.0	Sale
Sodium chloride	393			
Caustic soda	245			
Unknown salt	135			
Unknown substances (2, 3)	20			

The economic incentives for environmentally sound recycling recovery of components with net material value > $ 1/unit, suggests viability to extract gold, copper, steel, aluminum, palladium. The copper in CRTs > 60% of total intrinsic value are highly attractive for recyclers. The debris is passed on to waste dealers.

Table 6 : The intrinsic value of PC is mainly based on gold, palladium, silver, copper, steel and aluminum.

	Content in desk-top PC, Computer, (g/unit)	Av Material price ($/T)	Intrinsic Material value ($/unit)	Estimated recovery with present technol	Estimated recovery with BAT applicable	Net Matl value with present technology $/unit	Net Material value with BAT $/unit
Steel	6,737.501	253*	1.70	95%	95%	1.62	1.62
Plastics	1,579.545	310**	0.49	0%	0*	0	0
Aluminum	550.212	2,700	1.49	88%	78%	1.31	1.16
Copper	413.225	7,231	2.99	85%	98%	2.54	2.93
Zinc	25.940	3,400	0.09	0%	0%	0	0
Tin	19.573	19,800	0.39	0%	0%	0	0
Antimony	18.577	5,660	0.11	0%	0%	0	0
Nickel	12.700	37,200	0.47	0%	0%	0	0
Lead	6.585	2,730	0.02	0%	0%	0	0
Silver	1.702	550,000	0.94	0%	87%	0	0.81
Gold	0.260	22,400,000	5.82	30%	93%	1.75	5.42
Palladium	0.120	11,488,748	1.38	0%	91%	0	1.25
Chromium	0.015	2,010	0.00	0%	0%		0
Ceramic /others	371.909	-	-	-	-	-	-
Sum	**9737.860**		**15.88**			**7.22**	**13.19**

Table 7 : Economic incentives for environmentally sound recycling

Components	Content in CRT-TV, (g/unit)	Av Material price ($/T)	Intrinsic Material value ($/unit)	Estimated recovery with present technology	Estimated recovery with BAT applicable	Net Material value with present technology $/unit	Net Material value with BAT $/unit
Glass	17,043	0	0	0%	0%	0	0
Plastics	6,880	310*	2.13	0%	0*	0	0
Steel	2,990	253	0.76	95%	95%	0.72	0.72
Copper	900	7,231	6.51	85%	98%	5.53	6.38
Aluminum	598	2,700	1.61	88%	88%	1.42	1.42
Tin	31	19,800	0.62	0%	0%	0	0
Lead	22*	2,730	0.06	0%	0%	0	0
Nickel	6.7	374,200	0.25	0%	0%	0	0
Silver	0.62	550,000	0.34	0%	87%	0	0.30
Gold	0.04	22,400,000	0.85	0%	93%	0	0.79
Palladium	0.02	11,488.748	0.26	0%	91%	0	0.23
Ceramic /others	1,434	-	-	-	-	-	-
Sum	**29,900**		**13.38**			**7.67**	**9.84**

Environmental benefits provide stimulation to treat precious metals in PCBs and contactors in smelters in Europe or Canada; and export heavy metals. These smelters are equipped with off-gas treatment to minimize net emissions of hazardous dioxins, provide significant potentials in resource efficiency simultaneous to recovery of gold from 30% to 93% and for silver and palladium to 87% and 91% respectively. A 5.23 kg CO_2eq could be saved/ desktop PC compared to mining metal ores.

Table 8 Energy demand and greenhouse gas emissions of primary and secondary metal production for one desktop computer (without monitor and peripherals) (Environmental benefits)
CED = Cumulative Energy Demand, GWP = Global Warming Potential

International Journal of Advanced Scientific and Technical Research Issue 5 volume 7, Nov. –Dec. 2015
Available online on http://www.rspublication.com/ijst/index.html ISSN 2249-9954

Primary production	**Fe (steel)**	**Al**	**Cu**	**Ag**	**Au**	**Pd**
CED [kWh/kg]	8.231	57.02	15.14	455.86	82790	46276
GWP [kg $CO_{2\ eq}$/kg]	2.04	10.20	2.81	112.14	17,879.75	9284.30

Secondary production	**Fe (steel)**	**Al**	**Cu**	**Ag**	**Au**	**Pd**
CED [kWh/kg]	2.313	6.33	0.233	33.141	1935	1013
GWP [kg $CO_{2\ eq}$/kg]	0.40	1.32	0.10*	**Fe (steel)**	835.40*	437.57*

	Fe (steel)	**Al**	**Cu**	**Ag**	**Au**	**Pd**
Amount per device [g]	6,737.50	550.21	413.23	1.70	0.26	0.12
Recovery potential [%]	95	78	98	87	93	91

Environmental impacts of secondary production from the recycling outputs of 1 desktop computer

	Fe (steel)	**Al**	**Cu**	**Ag**	**Au**	**Pd**
CED [kWh/kg]	14.82	2.717	0.094	0.05	0.467	0.111
GWP [kg $CO_{2\ eq}$/kg]	2.54	0.57	0.04	0.02	0.20	0.05

Environmental impacts of primary production of the same amount of materials as from recycling of 1 desktop computer

	Fe (steel)	**Al**	**Cu**	**Ag**	**Au**	**Pd**
CED [kWh/kg]	52.68	22.33	6.13	0.675	20.03	5.05
GWP [kg $CO_{2\ eq}$/kg]	13.07	4.38	1.14	0.17	4.32	1.01

Saving potential through recycling of 1 desktop computer [absolute]

	Fe (steel)	**Al**	**Cu**	**Ag**	**Au**	**Pd**
CED [kWh/kg]	37.86	196.10	6.037	0.625	19.56	4.945
GWP [kg $CO_{2\ eq}$/kg]	10.53	3.81	1.10	0.14	4.12	0.97

Saving potential through recycling of 1 desktop computer [%]

	Fe (steel)	**Al**	**Cu**	**Ag**	**Au**	**Pd**
CED [kWh/kg]	20.0	24.44	27.22	25.84	27.22	27.22
GWP [kg $CO_{2\ eq}$/kg]	81	87	96	87	95	95

CED = Cumulative Energy Demand, GWP = Global Warming Potential

Going by sustainable and environment friendly best acceptable technology (BAT) more benign aqua regia process is followed by this author in another paper in more detail.

Table 9 : Chemicals requirement for 1 kg scrap gold purification (in the refinery)

a. 30% conc. HCl : 1960 ml
b. 70% conc. HNO_3 : 230 ml
c. $NaHSO_3$: 1600 g
d. Urea : 658 g
e. Oxalic acid : 457 g
f. $SnCl_4$: 2000 g .

Table 10 : Approximate theoretical value of components in the Input Material (in Ton)

Precious metals	Content , g/Ton	Typical value , $ / Ton
Ag	1224	460
Au	133	2674
Pd	237	2443
Cu	23000	287
Total		5864

Present gold price = $36708/kg (Rs 30 L / kg); Palladium = $ 22260/kg (Rs 13.5 L /kg); Silver = $ 530 / kg (Rs. 0.44 L/kg); Copper = $ 6.472 / kg (Rs. 500 / kg); Aluminum = $ 527/kg (Rs. 145 /kg) .

Revenues and expenses

A simple cost-benefit analysis for gold recovery in organized sector by cyanide leaching technique netted a value of gold of $ 20104/kg, a gross benefit in gold sales of $ 1021 / Ton. The raw material and auxiliaries costs are calculated/kg input material. The purchase prices relate to the formal market in India.

Table 11 : Approximate evaluation of total expenses

Input material	Content, kg/Ton	Rs/kg	From Rs / Ton	Up to Rs / Ton	$ / Ton
Input material	1000	50	50,000	68,000	1177
Substance containing cyanide (~20 %)	179	250	44,686	60,800	1053
Nitric acid	33	27	883	1,200	21
Sodium chloride	19	127	2,405	3,280	57
Caustic soda	12	32	379	480	9
Charcoal	105	350	36,694	37,440	624
Total expenses			135,000	171,200	2296

Using purchase price of a input material $ 1250-4150 / Ton, the net value for average contents works out $ 2700 /Ton. India to Europe Shipping cost of 20 containers x 8 T/container from Chennai to Europe ~ $ 1100 /container.

Table 12 : Eco-invent data on chemicals emitted to air from combustion of charcoal

Substance	Kg/MJ	Kg/kWh	g/kWh
CO_2	$9.15(10)^{-2}$	3.4×10^{-1}	$3.4 \times 10^{+2}$
HCl	$3.31(10)^{-6}$	1.2×10^{-6}	1.2×10^{-3}
HF	$1.24(10)^{-7}$	4.5×10^{-7}	4.5×10^{-4}
H_2SO_4	$1.00(10)^{-7}$	3.6×10^{-7}	3.6×10^{-4}
NO_x	$1.00(10)^{-4}$	3.6×10^{-4}	3.6×10^{-1}
SO_2	$1.00(10)^{-4}$	3.6×10^{-4}	3.6×10^{-1}

Table 13 : Chemicals (GHGs) emitted to air from shipping material

Substance	Kg/Ton/km
CO_2	$5.40 (10)^{-03}$
SO_2	$9.96 (10)^{-05}$
NO_x	$3.68 (10)^{-05}$

Referring to Table 14 below in general, ewaste recycling offers very attractive economic benefits at various scales with break-even point ~ 2.2 years and corresponding IRR = 47% . Looking at the gold recovery from mined ore with 2–4 ppm, the ewaste recycling practice justifies nation-wide drive to clean up environment, creating employment opportunity on regular basis, with government support and contribute to a great cause of national economy.

Table 14 : Economic feasibility for recycling ewaste (PCB) and sensitivity analysis in present study.

		Op cost 10% up	Ensure RMC	Optimal run	Prod price 15%	
Revenue / Expenditure items	For 27T gold	Proc 27 T PCB	Proc 20 T PCB	**Proc 35 T PCB**	Proc 40 T PCB	Proc 35 T PCB
Revenues						
Revenue from sale				Twice 15 Ton		
Gold	162	187	120	210	240	210
Silver	007					
Palladium	006					
Copper	011					
Other income		033			48	048
Total Revenue	186	220	**120**	258	**288**	258
Costs						
Fixed Costs						
Land	015	015	015			
Equipment	**020**	**020**	**020**			
Office building + computers / machines / appliance / vehicles	**015**	**015**	**015**			
	050					
Operating costs	062	**080**	068	092	105	113
Raw material purchase cost 27 T	007	**008**	006	009	012	014
Raw material collection & transport costs	002	002	002	002.6	004	004
Chemicals	004	004	003	005	006	007
Salary/wages	035	**038**	042	046	055	060
Power & fuel	003	003	003	004	005	006
Maintenance of office appliances + production facility	002	002	002	003	005	004
Insurance of office appliances + production facility	002	002	002	002	003	003
Waste Treatment + disposal cost	003	002	003	004	005	005
Working capital cost	004	**006**	005	007	010	010
Total Costs	112	080	068	092	105	113
EBDIT (Earnings before interest, depreciation, tax)	074	140	052	166	183	145
Finance cost	015	**015**	015	015	015	**015**
Depreciation	004	004	004	004	005	004
Tax	015	056	016	066	071	065
Profit / loss	**041**	**065**	017	**081**	**092**	**080**
NPV	87.35					
IRR	47 %					
PBP	2.2 years					

Table 15 : Estimates of NPV and IRR using investment made and expected cash flows from operation.

Year	0	1	2	3	4	5		
Cash flow	-121	41	81	92	80	65		
NPV	87.35	64.81	45.76	39.00	16.00	-6.00	-2.12	0
IRR	20 %	25 %	30 %	32 %	40 %	50 %	48 %	47 %
BEP	5 year	4 year	3.4 year	3.2 year	2.5 years	-	-	2.2 years

Sensitivity analysis carried out suggests that financial profits are going to be robust despite adverse conditions such as 15% dip in gold sale price, less utilization of plant capacity. If there is 20% dip in finished product gold price in the market place, simultaneous to finance cost burden hike due to inventory or delayed processing, most of the profit is wiped out. This brings out inherent characteristics of positives and negatives of risky precious metal business. Going by sensitivity analysis, it is most likely that a well managed and ragged project makes it cash rich operation.

Higher cash flow in the early years of project start up is most desirable for faster break even point. The profits from other precious metals (Au, Ag, Cu, steel etc.) recovery alter the economic feasibility more favourably.

Striking features of this project :

1. Availability of PCB/ewaste at price, government policy, competitors can be great challenge and threat to this business.
2. Tie up with gold refiners/scrap jewelry recyclers/electroplating/PCB manufacturers is desirable to de-risk ewaste /PCB supply.
3. Faster recycling process to roll funds to avoid finance burden for any costly inventory build-up.
4. Gold security is another biggest issue.
5. Best practices with environmentally benign technology depicts attractive profit in this project.
6. Recovering other precious metals as well (Pt, Pd, Ag, copper etc.) further improves profitabilit

Recovering other precious metals and base metals as well (Pt, Pd, Ag, copper, steel aluminum etc.) improves profitability. For the kind of input raw material ewaste PCB chosen in this study, a 35 TPY PCB processing seems optimum scale business. Beyond this larger throughputs do not yield proportionately higher profitability margins. Yet higher capacity utilization may owe to burden on plant & machinery, operating personnel, and more break down maintenance costs.

Ensuring availability of PCB ewaste tonnage at reasonable price, and new competitors pose great challenge and threat to this business. It is desired to tie-up with gold refiners, scrap jewelry, recyclers, electroplating, PCB manufacturers to de-risk raw material supply. Gold being very expensive, recycling has to avoid processing delay and product inventory to ensure faster rolling funds. Gold security is another biggest issue.

Conclusions :

1. Ewaste is global issue that needs to resolve social, economic, technical and environmental issues. It requires government support.

2. Recycling ewaste is a very attractive business proposal at various scale of operation.

3. Environmentally benign aqua-regia process > 20 Tons PCB provides flexibility and attractive profits.

4. The risk involved in this business is security of gold, project sensitivity due to as high as 15-20% decline in gold price or inventory build up and like can put this business in a tight corner.

5. To de-risk this business to some extent, it is desired to integrate this recycling ewaste (PCB) unit with jewelry works or tie-up with electronic goods manufacturers to absorb short term/seasonal shocks.

Acknowledgement:
Authors would like to thank Tata management for their support and valuable inputs.

References

Chatterjee, S. and Krishna Kumar; “Effective Electronic Waste Management and Recycling Process involving Formal and Non-formal Sectors”, Int. Jl. of Physical Sciences 4, p 893-905 December (2009).

Massimo Delfini, Mauro Ferrini, Andrea Manni, Paolo Massacci, Luigi Piga, Antonio Scoppettuolo : “Optimization of Precious Metals Recovery from Waste Electrical and Electronic Equipment Boards”, Journal of EnvironmentalProtection 2, 675-682 (2011).

Sanjeev Patil : “Recycling of Scrap Jewelry in Aqua regia :- A Case Study in Dissolution Kinetics”. International Journal of Advanced Scientific and Technical Research 1, (4) 162-172 Jan-Feb (2014).

Peters, M.S., Timmerhaus, K.D., and West, R.E., “Plant Design and Economics for Chemical Engineers”, 5th edn. McGraw Hill, New York (2003)

Smith, “Engineering Economy”, Iowa State University Press, Ames, Iowa (1968).