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COBALT RECOVERY FROM WASTE Li-ION BATTERIES: DEVELOPMENT AND ISSUES IN TECHNOLOGY TRANSFER

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ABSTRACT

The global consumption of Li-ion batteries is of approximately US$8billion annually and is expected to rise fourfold and reach 3400 metric tons by 2020 and four million metric tons by 2040. These batteries have a short life spam (2-4 years) and can result in huge electronic waste which is being considered hazardous for the environment. However, the waste lithium ion batteries of mobile phones contain many valuable metals also which need to be recovered for the conservation of natural resources vis-à-vis environmental protection. So the need of such technologies which can recover valuable metals out of it and the commercialization of that technology to the industry is highly desirable. The present case study deals with such a technology which can recover cobalt from waste lithium ion batteries and transfer of that technology to the industry. A detailed discussion with the scientist, industrial unit and the Central Pollution Control board (CBCB) led to a conclusion that administrative delays caused by human resources shortage and missing linkages are the reasons for delay in technology commercialization.

KEYWORDS : Electronic Waste, Technology Transfer, Recovery, Commercialization

In this present era of internet the use of electronic gadgets mainly mobile phones has increased enormously so as the generation of e-waste around world. This has increased the importance of technologies which could help in recycling of e-waste. Present study deals with such a technology which recovers cobalt from lithium ion batteries. This case study is done with following objectives:

- To understand how exactly such technology works at lab level and industry level.
- To understand process undertaken by industry to make technology ready for production.
- To understand issues encountered by industry to obtain necessary clearances from Government regulatory agencies to start production process.
- To understand expectations of industry from Government research institution and Government regulatory agencies for smooth production process.

Government research institutions can be an important source of technology providers for the industries. Recently the issue of commercialization of bench level technologies developed in Government research institutions has received a lot of attention. Generally a lot of innovations emerge from the research institutions which are being adopted by industry. The present study covers the technology "Recovery of Cobalt from Discarded Li-Ion Batteries of mobile phones" developed by National Metallurgical Laboratory (NML) at Jamshedpur. The project was sponsored byADV Metal combine Pvt. Ltd., New Delhi. After successful development of the technology it was tested at Metal Extraction and Forming (MEF) unit of NML and exclusive license was granted to ADV Metal combine Pvt. Ltd., New Delhi. The technology was scaled-up byADV Metal combine Pvt. Ltd. with modification to make it ready for mass scale production.

For any innovation to become successful many issues need immediate attention from the stakeholders' point of view(Edquist, 2011). In this present case one of the major concerns of industrial unit was the presence of unauthorized e-waste recyclers who posed threat to the business of authorized industrial units dealing with e-waste. This issue needs immediate attention for effective control of environmental hazards resulting from e-waste generation.

Also by Seers, D. (1979, The birth, life and death of development economics) for maximum exploitation of technologies Government should provide level playing fields among stakeholders. In Indian scenario due to presence of unauthorized e-waste recyclers this level playing field is absent. The key elements in successful diffusion of an innovation as-innovation itself, communication channels, time period and members of social systems (Rogers, 2010).

It can be observed that the demand domain of the system is not fully developed; this might be because of systemic and regulatory inertia, unauthorized recyclers, non-segregation of waste at source, improper waste disposal system.

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In order to realize the objectives of the study discussions were held with scientists who developed the technology and the industrial unit persons receiving the technology. Also discussion was held with Central Pollution Control Board (CPCB) officials as the technology deals with recycling of waste/discharged batteries of mobile phones.

Literature Review

Technology is that knowledge which can be used to produce something for which there is need (Hayek, 1941). Government academic and research institutions can become an important source of technologies for industry as they are constantly engaged in the process of knowledge generation through research. But the path travelled by the bench level technology to become a fully commercial able technology ready to go into industrial production is full of challenges and rather unpredictable. The complex process of technology transfer makes the technology difficult to transfer (Spivey et al., 1997). These challenges arise due to many factors. The work culture and interest of academia and industry are quite different. In most of the cases industry is not aware of the knowledge base generated at Government research institutions. Therefore establishment of technology transfer offices in most of the research laboratories and university (Siegel et al. 2004) is highly desirable as it benefits not only from economic but also from competitive perspective. The bench level technology is mostly working on lab level but is not able to perform as per the industry expectation when tried at higher scale (M. U Khan, 2012). Therefore a lot of developmental work on the technology is required to be done by the industry before it is finally ready to go into production. The availability of supplementary machinery and raw material is another issue. Technical support from Government research institutions in post transfer phase is another issue. Challenges arising to difficult and complex Government procedures are another factor. If a technology is viable at commercial level then only is successful technology otherwise there are n-number of technologies available in laboratory.

Need of recycling lithium Ion (Li-Ion) Batteries

Owing to the light weight, long lasting and large capacity, Li-ion batteries have become main power source which is not limited only to smartphones but also have wide application in portable electronic devices and electronic vehicles (Prioret et al., 2013). So the chances of generation of waste batteries will be high which can cause serious threat to environment. (Yu and Li, 2004). An effective recycling technology will not only help in dealing with this enormous e-waste but will also conserve the natural resource which goes into manufacturing of these batteries.

Globally use of cobalt as a metal component in Li-ion batteries has grown considerably (Dewulf et al., 2010). The global consumption of Li-ion batteries of approximately US$8billion annually and while looking at global consumption level of Li-ion batteries, the volume of e-waste generated as a result of Li-Ion batteries is expected to reach 3400 metric tons by the year 2020, a fourfold increase from 2013 levels (Wang et al., 2014). This is expected to increase to 4 million metric tons of lithium-ion cells by the year 2040 (Richa et al.,2014).

There batteries have a short life spam (2-4 years) and can result in huge electronic waste which is being considered hazardous for the environment. However, the waste lithium ion batteries of mobile phones contain many valuable metals also which need to be recovered for the conservation of natural resources vis-à-vis environmental protection.

With global sales approaching US$8billion annually Oladele A. Ogunseitan and colleagues have concluded that with short life spam (2-4 years) of Li-ion batteries in portable devices can result in huge electronic waste. Li-ion batteries are considered hazardous as they contain metals like cobalt, copper and nickel. Therefore a stronger government policy at the local, national, international levels is highly desirable to encourage recovery, recycling and reuse of lithium batteries material.

Recycling of Li-ion batteries

The current recycling rate of Li-ion batteries are very poor. The metals present in these batteries are typically recovered in a high- temperature process that fuses them together as an alloy, sometimes using plastic casing as a fuel. The major part of metals in smartphone batteries come from primary mining, mostly from processes that cause great environmental damage. Collection of used Li-ion

batteries is the major problem since it is also thrown in the garbage from where rag-pickers collect. There is no regularized or standardized method available to collect it. Also sometimes people tend to keep them unused with them in households and the precious metals get trapped with them lying unused for a long period of time. With increasing digital network around world the generation of electrical and electronic waste has become a global concern making an effective recycling technology is highly desirable.

Over the last decade a lots of research has been done on how to efficiently recover precious metals from Li-ion batteries keeping in mind the environmental concern. Most of these recovery techniques are based on bio-metallurgical, hydrometallurgical and pyrometallurgical chemistry (Contestabile et al., 2001;Jha et al., 2013).

The Present Case Study

The present case study deals with the technology "Recovery of Cobalt from Discarded Li-Ion Batteries of mobile phones". The technology was developed by CSIR-NML and was successfully transferred to ADV Metal Combine Pvt. Ltd. New Delhi. The idea was conceived by ADV Metal Combine Pvt. Ltd. and the task of developing the technology was undertaken at CSIR-NML Jamshedpur.

A detailed discussion with the scientist, industrial unit and Central Pollution Control Board (CPCB) was held to in view of the objectives of the case study.

The technology "Recovery of Cobalt from Discarded Li-Ion Batteries of mobile phones" is claimed to recover upto 95% pure cobalt from the Li-ion batteries.

Discussions with scientists and the industrial unit were held to understand the development of technology, its subsequent transfer and commercialization. Discussion with Central Pollution Control Board (CPCB) officials was also held to understand the regulatory aspect of e-waste recycling/dismantling and existing scenario of e-waste in the country.

Discussions with scientists were held to understand the working of technology, the raw materials required to use the technology and the source of raw material, how the formal interaction with industry initiated, experiences about the collaboration with the industry, prototype development, challenges faced during the development process, the testing of the technology, environmental consideration kept in mind while developing the technology, unique features of the technology, availability of same kind of technologies in the market, suggestions for enhancing technology transfer to industry and usefulness of the technology for society.

Similarly discussions were held with industry people on the current problems faced by them after receiving the technology and putting the same into production, raw material availability, economic viability of the technology, modification done to the technology, obtaining necessary clearances from Government departments, the environmental concerns in context of e-waste.

The discussion with the CPCB officials was held on rising issue of e-waste in India in view of increased use of information and communication technologies because of Government initiatives like Digital India, the procedure adopted in dealing with clearance requests received from industry, the problem of unauthorized e-waste recyclers, steps being taken by Government to deal with unauthorized e-waste recyclers, the latest technologies available to deal with e-waste, the current research areas where Indian Government research agencies should focus in order to deal with e-waste effectively.

About the Technology

An effective e-waste recycling technology should be able to recover maximum components from e-waste for future use leaving behind minimum waste. For this recovery and or reuse the valuable material out of e-waste has to be maximized, also the process should be least hazardous for the environment. The Li-ion battery contains cadmium, copper, aluminum and other non-metals, therefore a prolonged stay in the vicinity of dumping sites of these e-waste and working on Li-ion battery related operations may harm the nervous and respiratory system.

The present technology uses hydrometallurgy process for the recovery of cobalt from waste Li-ion batteries. In this process metal is extracted using sulfuric acid as it's less hazardous to the environment as compared to other material (Jha et al., 2011). Hydrometallurgical processes are considered better than other processes

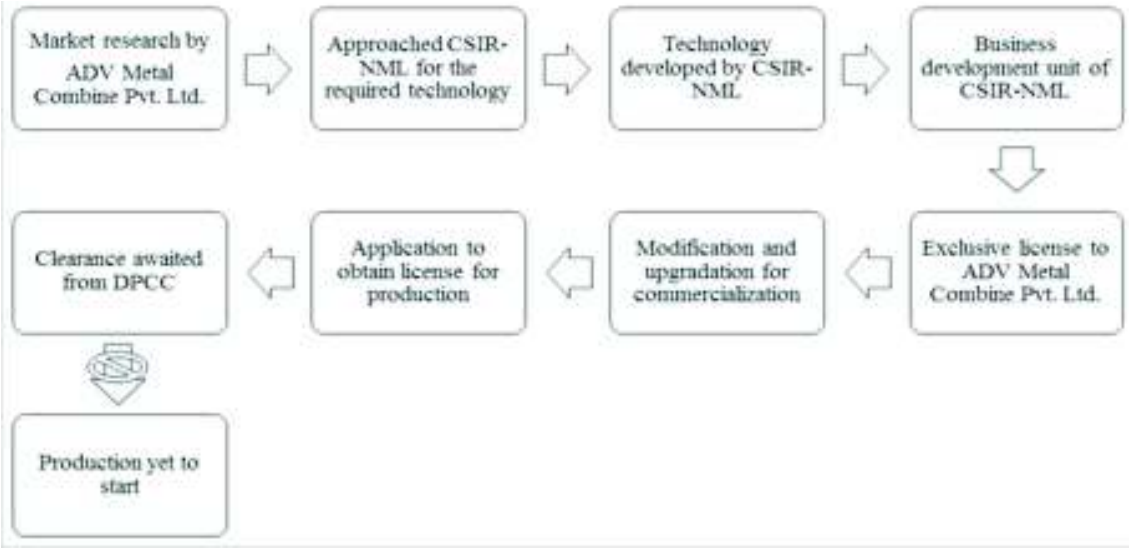


Figure 1: Overall flow of technology

because of high proportion and purity of recovered metals, low energy requirement and minimal air emission.

The current technology involves dismantling of Li-ion batteries, classification, and size reduction of cathode active material and leaching of waste. The recovery process is optimized by controlling various parameters like temperature, concentration of acid and pulp density (Jha et al., 2013).

ANALYSIS AND DISCUSSION

Discussion With Scientist

In view of the environmental regulations, availability of limited resources of cobalt in nature and role of cobalt in meeting ever increasing energy demand, it was realized that an environmental eco-friendly process is needed for the recovery of cobalt from lithium ion batteries of mobile phones. Mobile phone batteries constitute a major source of e-waste containing rare earth metals like cobalt, lithium, nickel and if these metals can be recovered in the eco-friendly manner following zero waste concept it will be extremely beneficial for industry as well as to address environmental concerns. Cobalt has many useful applications e.g. being radioactive in nature cobalt-60(a type of cobalt) can be used to treat cancer; some food items are also treated with cobalt 60 radiations for preservation purposes.

The project for development of technology for recovering Cobalt from Li-ion batteries was the result of collaborative work between Industrial unit (ADV Metal Combine Pvt. Ltd.) and scientists at NML Jamshedpur. The industry approached NML for the collaboration.

In the conventional process the cobalt was recovered from Li-ion batteries through pyrometallurgical process and the waste batteries after the recovery were sent as land fill. The technology developed by NML used hydrometallurgical process for recovery of cobalt. After development of the technology it was tested for feasibility, purity, economic viability, environmental aspects using at NML.A prototype for the technology was developed by NML and tested for viability.

Scientists also described various benefits of the technology in view of the huge generation of e-waste in recent years. The current technology developed by CSIR-NML has been claimed to be cost effective process and less hazardous as compared to existing processes. It can help in reduction of E-waste significantly through efficient recycling. The current scenario is dominated by unauthorized recyclers resulting in a lot of Li-Ion batteries being dumped in garbage and contaminating the soil.

Discussion With Industry

The industrial unit invested in the technology development process. They were extremely satisfied with

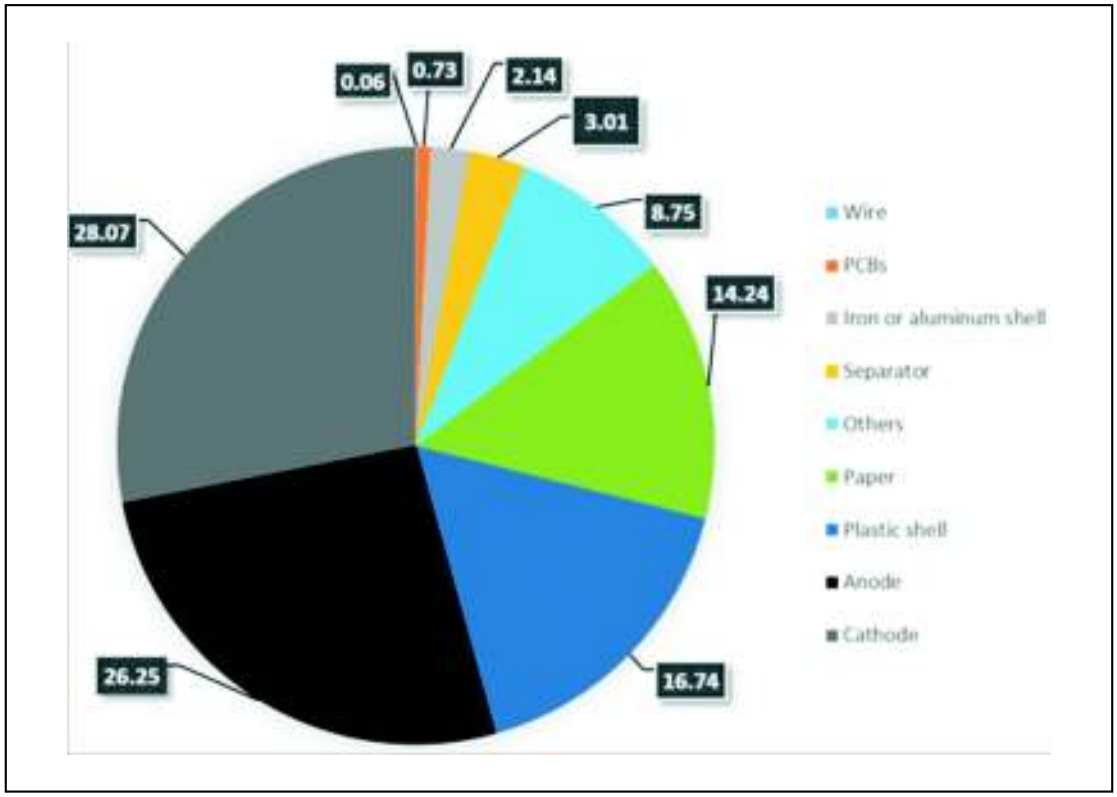


Figure 2: Average Component Ratio of Various Li-ion Batteries(Source: Zeng et al., 2014)

their prior experience with NML where they received the technology "Recovery of Gold from waste mobile phones and scraps of various equipments".The industry has received the technology for the "Recovery of Cobalt from discarded Li-Ion batteries of mobile phones" on an exclusive license basis. In case of current technology the industrial unit had to upgrade the technology at industry scale. A lot of modification was done to the technology as the technology provided by NML could only recover 60-70% of the cobalt present in the e-waste material. The industrial unit perfected it up-to 95% pure cobalt recovery level. The industry also established a pilot plant to validate the technology. Li-ion batteries used as major raw material. Some of the other raw material had to be imported from abroad. Some of the chemicals used as reagents and extractants while testing and upgrading the technology had to be imported. Outside experts were also consulted. The industry claimed to have perfected the technology up-to a zero waste level and there is no waste to dispose after recycling. Currently the industry is facing difficulties in collecting Li-ion batteries, their major raw material, as is thrown in the garbage where rag-pickers collect it. There is no standard and regularized method to collect these Li-ion batteries.The industry also requires license to recycle these e-waste, although they have applied for license with State Pollution Control Board (SPCB). Since the industrial unit is still waiting for the clearance from State Pollution Control Board (SPCB), the production process has not started. Therefore industrial unit is yet to start earning from the technology. Apart from getting the clearance, the industrial unit felt the other major challenge is getting the raw material in large scale. However the industrial unit was satisfied with the technology as becomes clear from the remark from industry "Sufficient facility is available to undertake such research work, one can always approach NML if you find any difficulties related to technology that you have received".

Discussion with Central Pollution Control Board (CPCB) Official

The Central Pollution Control Board (CPCB), was constituted in September, 1974 under the water (Prevention and Control of Pollution) Act, 1974.

E-waste contains many hazardous components but at the same time they contain many precious metals as well as useful material of which are economically beneficial. These include plastics, iron, glass, aluminum, copper and precious metals such as silver, gold, platinum, palladium, lead, cadmium and mercury etc. Recovery of these metals and materials through unscientific practices may pose risk to health and environment during handling and recovery operations, as it involves open burning, acid dissolution and dumping of the left out acids or material in river, drains or lands.

Therefore the Govt. of India has come-up with regulation known as e-waste (Management and Handling) Rules, 2016 announced on notification dated 23rd March, 2016.The objective was to minimize the unscientific recovery of metals and materials from e-waste and to promote regularized e-waste recycling process which is more scientific in nature and less hazardous. A provision has been kept in the regulation to grant license to the industrial unit for e-waste recycling within ninety days of application. Before applying for license for e-waste recycling the industrial unit should meet the requirements in accordance with the rules and regulation. It is difficult to get such clearances in Delhi because of the stringent guidelines of adhering to Delhi masterplan which contains strict land use guidelines. However it is easier to get such licenses to operate in Noida, Faridabad or other places and there the industrial unit can apply for license. CPCB Data shows no license has been granted to any operator for e-waste recycling in Delhi. However, there are many unauthorized e-waste recyclers operating in Delhi NCR.

As per the discussion with CPCB, unauthorized recycling in India can be classified mainly into following two categories:

1) Metal recovery using acids and burning
2) Opening of the equipments using screw drivers

Since these practices are extremely hazardous in nature causing harm not only to the environment causing adverse effect to the health of the workers involved in it. These needed to be stopped immediately. But at the same time looking at the large number of people involved in this type of recycling activities for last 30-35 years, the socioeconomic aspect of the problem should also be taken into account while dealing with it. Therefore while formulating policies for effective handling of e-waste, socioeconomic aspects have to be taken into account by the concerned ministry and agencies like CPCB.

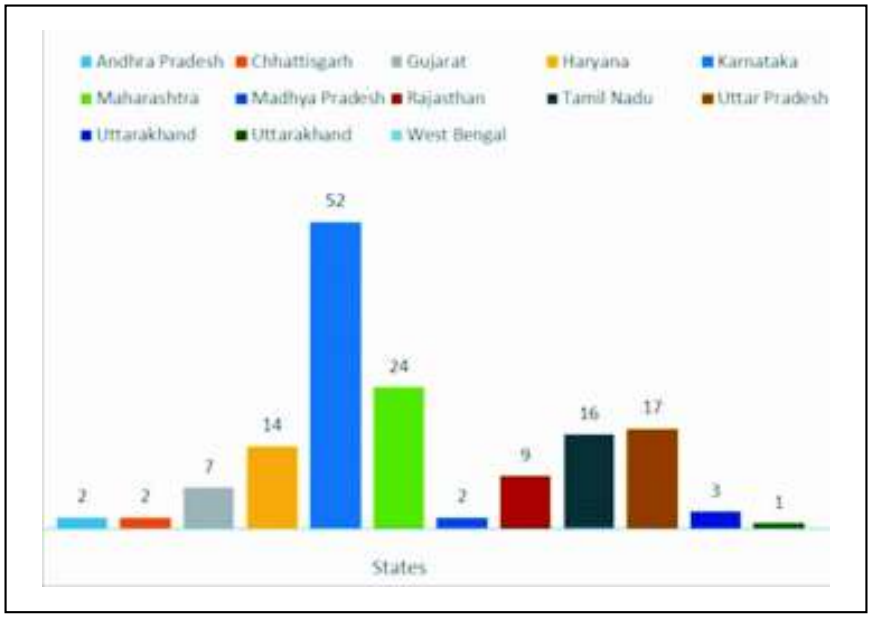
Keeping this into consideration CPCB is actively engaged in spreading awareness about the hazardous effects of unscientific processes and environmental regulations. Establishing a common facility for unauthorized e-waste recyclers to recycle their waste where they can bring their raw material for processing. Already such common facilities have been setup at district levels in few states. These initiatives will help in bringing unauthorized e-waste recyclers into main stream. Government is also working on to minimize the flow of e-waste to the unauthorized recyclers and making the formal system more robust. This will help in increasing flow of raw material to authorized e-waste recyclers.

In order to stop unauthorized recycling CPCB carry out inspection at unauthorized recycling sites and report to the concerned state government about the illegal recycling, resulting in closure of such units. But it was observed that the closed units used to shift to another site and start operating from there. As they keep on moving so it's also very difficult to control them. Another aspect of the problem as pointed out by CPCB officials that these unauthorized recyclers sell their goods to unauthorized persons which makes it very difficult to check and control.

Another issue is the shortage of manpower at agencies like CPCB which makes it difficult to deal with applications received for licenses and other activities of these agencies. Which can be relished upon looking to the number of registered e-waste recyclers/dismantler units in India (Figure 3).Strengthening of SPCB/SPCC by recruiting more and more manpower and up-gradation of technological equipments being used by these agencies can also be helpful in dealing with concerned issues.

CONCLUSION

Recovery of cobalt from Li-ion batteries through the process as developed by NML Jamshedpur presents following immediate benefits:



Source: CPCB data as on 14-10-2015

Figure 3 : Registered Unit of E-waste Recyclers/Dismantler in India

- Recovery of cobalt as precious metal in more pure form.
- The less hazardous process for recovery of cobalt.
- Removal of Li-ion batteries from open environment and their effective disposal by industry in a closed environment after the recovery of cobalt.

However following challenges were faced by industry in the overall process of developing the technology and putting it into production.

- Large number of unregistered e-waste recyclers processing e-waste in unscientific manner
- Challenges incollection of Li-ion batteries from waste
- Obtaining necessary clearances from Government regulatory agencies for starting the production using Government technologies. In present case the recipient of the technology was not able to start production because of delay in obtaining necessary clearances from Government regulatory agencies.
- Challenges faced by industry in up-scaling the technology for meeting bulk production requirement with regard to availability of raw material.

These findings suggest the need for effective policy at local as well as national level to strengthen recovery, recycling/dismantling and reuse of Li-ion batteries. These may include increasing awareness level of unauthorized e-waste recyclers about the hazards involved in the unscientific process for e-waste recycling through Li-ion batteries and the laws related to e-waste re-cycling.From scientist point of view the development of the technology was a collaborative effort which increased the level of networking between industry and Government research institution. It increased industry's awareness about ongoing research in Government research institutions and also scientists in Government research institution were able to understand the industry dynamics. All this can be useful for any future collaboration between the two entities.

Finally the new technology developed by NML scientists has many advantages, before up-scaling the technology to a mass level usage, the interests of the large section of population involved in unauthorized recycling need to be taken into account. The possible approach would be to make these unauthorized recyclers aware of the advantage of the technology developed by NML Scientists which is based on scientific methods; and encourage them to use it instead of their current methods.

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