Establishment of Pilot Line
for
Rare Earth Mineral(s) Separation from Multiple feedstocks

A Project proposal to Ministry of Mines
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Institution: Nonferrous Materials Technology Development Centre (NFTDC)

1. Introduction:

Rare Earth bearing minerals, their beneficiation, separation as mixed chlorides, followed by separation of individual oxides is of urgent need. Monozite, a minor mineral in HMS of beach sand resources after recovery of primary minerals, namely ilmenite, Rutile, Zircon, Sillimanite, Garnet mostly cater to Low REEs (La, Ce, Nd, Pr) while HREEs comprising of Dy, Tb etc are almost non-existent. In Gujarat and Rajasthan, a few new finds show some potential for HREEs which are yet to be established in detail with drill core samples and further studies. In the meantime, efforts have been made to obtain resources from abroad in the form of off-takes, asset acquisition from Africa (S Africa, Zimbabwe, Burundi), Australia (Lynas, other western Australian sources), Sri Lanka and Mongolia. Myanmar has the best resource for HREEs in ionic clays and in particular for Dysprosium (Dy) and Terbium (Tb) which are crucial alloying additives to (Nd-Pr) Fe B magnets of higher grades.

Currently IREL produces 400 TPA of Nd Oxide which can at best cater to 1000 TPA of RE magnets of lower grades, while the demand for RE magnets by 2030 is pitched at 20,000 TPA for nearly 20 million **e**-vehicles. Even the target of 10 million e2W and e3W calls for 8000 – 10000 TPA of magnets which will demand a supply chain resilience of 3000 TPA of Nd/Pr + Dy/Tb Oxides. Higher grade magnets requiring 3-5% Dy and 2-8% Tb still face a massive challenge. Therefore, the need for augmenting raw materials supply chain in terms of multiple feedstocks of ores/concentrates, so as to obtain oxides and metals is to be taken up on priority.

2. Objectives:

- Enhance the technical infrastructure in beneficiation and SX lines in NFTDC to cater to recovery of REEs and dovetail it REPM manufacturing line with emphasis on major six MREOs (Magnetic RE oxides), namely Nd, Pr, Dy, Tb and Sm+Gd.

- Establish Pilot plant Line with all necessary equipments for beneficiation and REE oxide production at appropriate scale and size (100 kg batch input feed) to handle multiple feedstock containing REEs, covering physical separation, beneficiation and solvent extraction.

- Conduct process optimization for different feedstocks at pilot scale.

- Establish 100% feedstock utilization with by-product manufacture as per the salient features of feedstock.

- Techno-economic studies as per need of the CoE industry members

- Continue the operations of pilot plant as per evolving project requirements from clients and CoE industry members.

- Enable concurrent setting up of commercial scale plant for REE oxide plants with industry partners so as to achieve augmented domestic production of 1000 TPA by 2027-2030 from secondary and tertiary sources.

3. **Augmenting Supply Chains for REEs – Mission mode Initiative by NFTDC with CoE Industry Partners**

NFTDC along with Midwest has set up the first end to end commercial RE Magnet Manufacturing Line of 500 TPA magnet production that is going into operations in early 2026. This is being expanded to take up the magnet production to 5000 TPA and beyond by 2027-30. This figure alone translates to raw material requirement of nearly 2000 TPA of Nd/Pr Oxides and 150 TPA of Dy/Tb oxides which is a bare minimum. NFTDC CoE has drawn up REE Mission Plan with an aim to usher in at least three commercial level of REE materials processing plants to reach this target with operations for 10–15 years in a stabilized production.

NFTDC has been operating a RE Magnet pilot plant for nearly 2 decades starting with Nd, Sm metals and has recently set up the aforementioned commercial production plant with industry partnership for a 500 TPA REPM facility staring from Nd/Pr oxide. This is first demonstration commercial plant in the country. Since, NFTDC has a strong nucleus in RE materials to RE Magnets, the gaps in magnet pilot, up-coming commercial plant together with up – stream processes for separation any feed stock that has adequate REE values is being addressed. This endeavour will give the end-to-end processing of RE materials in large quantities.

Given the difficulties faced by India due to embargoes on RE materials and in particular HREEs, it is appropriate and timely to reinforce NFTDC with up-stream facilities that will cater to separation of RE minerals, oxides for metal recovery from all three sources, namely (i) primary from ores and (ii) secondary from residues, wastes, tailings etc and (iii) tertiary from End of Life of Products (EOL) such as used magnets . The three sources shall be both domestic and from abroad so as to keep all options available in the mix of raw materials feedstock to reduce vulnerability and supply chain risks.

The pilot line is needed to handle raw materials from multiple sites with varying phase and tenor in primary ores, secondary and tertiary sources. In this proposal two specific secondary categories with high potential for REE recovery have been tied up by our industry partners to obtain feedstock as well as go towards final commercial plants at the earliest. NFTDC CoE is thus implementing the augmentation of REE supply chain in a mission mode and concurrent engineering to reach commercial scale production of REE oxides with industry partners. This proposal addresses enhancing of both capability and capacity in RE Materials.

3.1 Secondary Sources and Initiatives of NFTDC – CoE

NFTDC led CoE industry members, viz Midwest, SCCL, Coal India and Altmin have already taken on-ground initiatives to augment the raw materials supply chain of REEs in India and in addition get into agreements for investments and offtakes from abroad. NFTDC has been analysing samples from India and abroad (Africa, Brazil, S Lanka, Myanmar, Australia) and has found Rare Earths and in particular HREEs in African and Myanmar samples, while S Lankan samples hold promise of Dy in some locations. With regard to LREEs, NFTDC and Industry partners are enabling Kerala Minerals and Metals Ltd (KMML) and AP Minerals Corporation to set up REE processing plants in PPP mode and the first initiatives are taking shape in first quarter of 2026. NFTDC also developed process flow sheets based on the resource and has also selected the supply chain for scale – up with industry partners as given below.

3.2 Residue (mineral) Based Resources

The first major source is (i) the residue containing monozite after removal of major minerals of ilmenite, rutile, zircon, garnet in beach sand minerals (HMS) etc in Ti/TiO2 plants and the consortium has already moved in this direction with both domestic and resources abroad. The first focus in this proposal is therefor is on the residue from Ti/TiO2 plants and other such residues that cross the threshold values as well as the availability of large quantum of resource as elaborated in subsequent sections. This endeavour will quickly make available LREEs and smaller quantum of Dy in the next two years itself once the pilot plant and entry level demonstration commercial plants ensues as envisaged by NFTDC CoE and its partners.

Other sources in this category are (ii) erstwhile tin mine ore burden and slag – tailings; here the monozite occurs along with columbite / tantalite minerals as minor minerals of cassiterite Sn deposits in Brazil. (iii) another potential resource, namely phosphogypsum that is a residue from phosphoric acid and fertilizer plants. The potential of Sn tailings and phosphogypsum have to be further studied as they contains more of La + Ce and Y and less of Nd/Pr and Dy/Tb before large scale up and investment level decisions can be taken. The proposed pilot line can also handle and study these latter two sources in selected campaigns with pre – treatment in physical beneficiation

3.3 Clay hosted REE resources

The second major category is the clay-based secondaries containing REEs above a threshold value. Ionic clay hosting REE and clay in coal seams are the two main secondary sources in this category. Clay hosted REEs are either ionic (weathered rocks forming sedimentary clay as sedimentary basins with REE ions hosted in clay) or clayey part of coal seams wherein either REE mineral particles or ions are hosted in clay part of the seams. Organic part of the clay may also host some REEs. Coal based REEs end up in fly ash after undergoing high temperature induced phase changes that make it difficult to extract. It is easier to recover from the clayey part, and it has been one of the foci of this initiative.

Myanmar and southeast China deposits are ionic clay hosted REE deposits that contain the highest HREEs in the world and till date they are the only ones serving as source for Dy and Tb. Just a few months ago in second half of 2025, significant ionic clay deposits were found in Brazil and Chile. Ionic clays hosting REEs and monozite residue after separation of ilmenite and rutile are the two best secondary sources for HREEs and LREEs respectively.

A mention is to be made about fly ash based REE resource. As it goes through high temperatures, phase changes occur and glassy phases form. REEs gets locked in these regions and it requires strong mineral acids and dissolution of matrix to a significant extent to recover the REEs.

To surmise, the resources are all secondary which fall into two major categories, namely co-occurring minor mineral of REEs as monozite (phosphate) or carbonate bearing residues or clay hosted REEs.

3.4 Tertiary Source

A tertiary source is RE Magnets in EOL products such as HDDs, windmill generators and MRIs and small magnets from speakers and other devices. HDDs are no longer made, and life cycle of windmill generators and MRIs are more than 15 years, and those magnets are returned to the same products in recycle mode. Recycling of RE magnets follows a simpler process route of hydrogen decrepit and remelting with alloying element corrections in NFTDC recycling process. In-process reverts which averages 20-25% in the REPM plants, this practice is already done. Elaborate flow sheets of acid leaching are unnecessary. In the case of small magnets, grade separation is done using portable XRF or automated XRF based sorting lines to distinguish ferrite, AlNiCo, SmCo and NdFeB with and without Dy+Tb grades. NFTDC has already done the work in this category as part of the REPM plant and therefore, no funding is asked for except the portable/tabletop XRF for rapid sorting. While in-process reverts are routinely handled, a major difficulty in EOL device sourced magnets is the collection at large scale to support a plant level operation. A stand-alone plant cannot be envisaged only based on used EOL magnets. Thus, programs of Magnet to Magnet can be easily dovetailed to upcoming REPM lines and a separate plant is not viable.

NFTDC studied extensively both categories of secondary resources, viz (a0 residue mineral based – MIDWEST /KMML/AP), (b) clayey and shale part of the coal seams from its CoE industry partners as well as from abroad and eventually zeroed in on potential points that cross the threshold value and developed flow sheets for further scale up.

4.0 Threshold Requirements and large-scale availability of secondary REE sources catering to scaled–up REE Oxide Plant.

Basic criteria/metrics (fitness function) were chosen to freeze the source materials, namely

(i) large scale availability of the secondary resource and

(ii) threshold levels of NdPr and /or Dy/Tb and/or Sc present (not total REE which is misleading) >> for residue containing monozite & clay hosted

(iii) beneficiation potential of the source material for upgrading at least by 10–20X.

It is generally found that La, Ce and Y oxides are present in larger quantities, and it tends to mislead the selection of potential source. A better metric that is currently being adopted internationally is MREOs, viz magnetic rare earth oxides (Nd, Pr, Sm, Gd, Dy, Tb) in lieu of TREOs or total Rare Earth Oxides. Ratio of MREOs to TREOs is another metric that is useful as it determines the quantum of separation of nonmagnetic REOs that is required. Given the priority for Nd+Pr and Dy, NFTDC evolved a threshold metric of MREOs comprising of Nd+Pr + Dy.

Threshold in terms of REE content is to be based on Nd+Pr contents and if Sc, Dy and or Tb (higher value REEs) are also present, technoeconomic potential gets enhanced. Sm + Gd is another pair that enhances the metrics.

Two different threshold levels are required for residues containing monozite and the clay based REEs, the reason being the beneficiation and extraction process flow sheets differ for the two categories. In the case of former, the existing monozite residue from Ti/TiO2 plant itself is at 25% and nearly 15-20% of that resource is Nd/Pr and Dy stands at 500 – 1500 ppm.

Regarding the second category, from extensive past experience, it has been determined by NFTDC that at least 150 ppm of Nd+Pr (+ Sc, Dy/Tb) should be present in the clay based secondary resource, before it can be considered even for further study. Secondly, beneficiating the resource by 10-20X, takes the content to 1000 – 2000 ppm which is threshold for a potential plant level capacity development. With advent of advances in froth flotation in combination with HTS and WHIMS, it can be upgraded 100 X taking it to percentage levels. Clay based

REEs subsequent to beneficiation go for simpler direct dissolution with ammonium sulphate or magnesium sulphate without the need for strong mineral acids.

Based on this fitness function, the following four sources were taken up for implementing the action plan for recovery of potential Nd+Pr and Dy/Tb. Thanks to elaborate prior work NFTDC, these four potential supply routes are now frozen for focussed action plan with top two on priority followed by third and fourth source.

REE values:

(i) REE bearing tailing / residues from Ti/TiO2/Ilmenite – Rutile plants

(ii) REE containing Coal waste /ore burden and ionic clay hosted REEs >> Clay based (200 ppm of Nd+Pr + Dy + Sc)

(iii) In-plant reverts (magnet slurry) and rejected magnet Recycling >> 24% Nd+Pr & 2-3&Dy

(iv) REE residues from tailings & ore burden of erstwhile Sn plants (Medium Tenor: > 1000 ppm of Nd+Pr +Dy/Tb + Sc)

By Products:

It is worth noting that while whenever, secondary resource based REE materials processing is undertaken, nearly entire quantum of the input is to be evacuated as less than 1% of the feedstock is extracted. Therefore, by-product development is crucial. NFTDC developed advanced ceramics as by products in the case of clay-based feedstocks which is elaborated in the subsequent sections. It not only significantly enhances the techno-economic feasibility but also serves a good metric for pre and post processes and plant sizing.

In the case of monozite bearing residue, smaller quantities of other minerals such as ilmenite and zircon are separated up front and 33% sand / lighter minerals are benign. Any residual Th is handled by the industry at site as per AERB norms. This has been tied up by KMML.

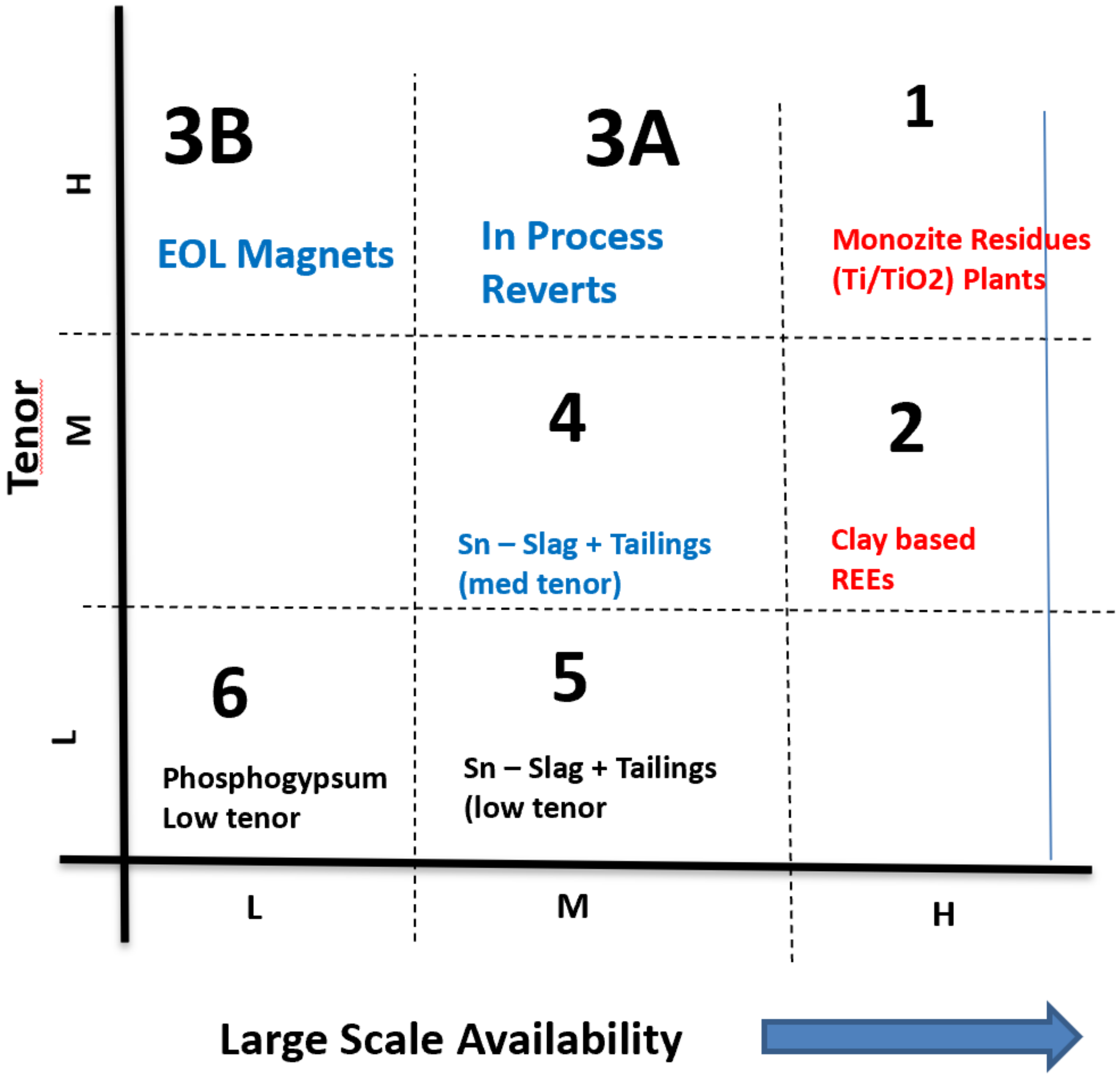


Figure: Ranking of Secondary /Tertiary REE resource (Tenor vs Availability)

The above figure summarizes the thresholds in terms of tenor and availability of the REE resources, and the preferred ones presently are in 1, 2, 3.

5. Need for Establishment of Pilot Line for REE Minerals and Materials Separation & Recovery and its salient features.

Pilot plants are considered as the crucial gateway for taking go / no go decisions for further scale up to an eventual commercial plant establishment. NFTDC being a technology development enterprise, was a pioneer is establishing the Technology Readiness Levels as early as late 1990s in India for a gamut of material to products to plant endeavours. Pilot plants in NFTDC are generally at 100 – 200 TPA or 1-2 TPD feed/output or 100 – 500 kg per batch equivalent based on case-to-case scenario. In the case of advanced alloys for strategic applications, output is taken as basis and for ore/conc/feedstock cases input is taken as basis. Thus, reactors, filters, furnaces and multitude of process equipments are appropriately sized and an optimized manufacturing line is established for product. Thus, Materials + Process + Product + Plant paradigm evolves in a holistic systems approach.

5.1 **Pilot Plant Metrics** >> **NFTDC Model**

The pilots are done to establish the following and all projects of NFTDC have pilots (TRL7-8) as the main activity/deliverable leading to establishment of commercial plant (TRL-9) in a concurrent engineering mode. The pilot plant in this case also has the industry partners involved from the start. NFTDC has a fine-tuned work break down structure (WBS) system for all its developmental activities and in particular for pilot plant which are at TRL 7-8. This model is to be distinguished from the routine R&D projects that are at lower TRL.

Overall Work Breakdown Structure (WBS)

Plant & Machinery

(i) Sequencing of unit processes and process-equipments leading to a potential manufacturing line – modules + sizing >> installation and commissioning

(ii) Handling variations/changes in the feedstock – supply chain issues >> Raw materials characterization; consumables line – up and batch readiness.

Operations related WBS

(iii) Consumables and their optimization

(iv) Product Yield, recovery at various stages optimized in terms of process parameters

(v) Energy consumption, chemical consumption and productivity

(vi) Overall optimization of process parameters for rendering a robust process line.

(vii) Product characteristics (including by-products) to be evaluated in terms of specifications (chemical composition, impurity levels, particle size, morphology, microstructure as per the case) and batch to batch consistency to be eventually obtained.

(viii) Establishment of ETP protocols and targeting zero discharge

(ix) In-process quality control – incorporation of sensors + DAQ – Evolution of QC/QA protocols: Process – Product integration and optimization.

(x) Documentation of Process – Product Integration >> leading to ISO & NABL accreditation for plant as well as readiness for Type Certification.

Techno-Economics related WBS

(xi) Detailed data generation for techno-economic study starting with preliminary data at the start of the pilot.

(xii) Data generation for basic engineering package for the plant (mass – energy flows)

Next Level Design related WBS

(xiii) Concurrent design of the entry level commercial plant &

(xiv) Industry partners to start the next level plant at their site with advanced planning right from start.

(xv) Speedy implementation and time compression (achieved by NFTDC in many of the previous pilots).

5.2 Salient Features of Multiple Feedstock & Multi-Metal Extraction REE Pilots >> Flexible Manufacturing Scheme.

In conventional cases, one considers a linear pathway in scale–up to pilots based usually on a single source of raw material and with a straight jacketed process flow sheet dedicated to that source. However, in the case of rare earths and critical materials, multiple feedstocks and multi – metal extraction is the norm. Therefore, pilots in these cases are to be designed in a such a way to treat the multiple feedstocks in more generic unit processes as pre-steps of concentration in Stage-1 followed by a more standardized recovery in Stage–2 with digestion (thermal + Hydromet) to bring the valuables in to an aqueous phase for separation in Stage–3 of multi elements and finally in Stage–4, a customized step for by-product manufacture as per the feedstock. This paradigm offers a more flexible manufacturing solution wherein the tenor of the feedstock and its variations can be effectively handled in Stage-1&2 while in stage -3, the elemental separation line is to be tuned to only gpl levels and in Stage-4 dedicated by-product manufacture is to be undertaken.

We have already segregated the REE feedstocks into two major categories as being based on mineral residues and clay hosted. The Stage-1, concentration step differs between the two categories only in terms of combination and sequencing of generic unit processes as in gravity, magnetic, electrostatic (HTS) and flotation unit processes (described in the subsequent sections). Here, in order to handle multiple feedstocks, the material is moved between the unit processes in a campaign mode for each feedstock while the equipments are stationary as four major unit processes. The sizing and magnetic and HTS parameters are kept at a larger level to the handle the most demanding feedstock and are also in tuneable mode. This approach gives the maximum flexibility. A noteworthy difference is in the nature of sequencing >> in the case of mineral residues, other minerals are separated, while in the case of clay it is much more of concentration of particles that host the REEs with the above four-unit processes and equipments. In the case of clay, separation of carbon, sulphur and iron oxide a priori which is simpler and can even be handled at mine pit site. The lines are not dedicated, but fine – tuning of parameters in the unit processes and equipments are done for the two categories.

In Stage-2, in the digestion part, only lixiviants are different and they get standardized as a module for the two categories with former having a thermal part while the clay part does not. Therefore, additional sub-steps happen in the case of mineral residues, while in the case of clay-based ones, it is much simpler and easier though the tenor is lower.

In Stage-3, which is SX based units, sets of units run first in campaign mode for each feedstock, as the gpl levels of solutions and matrix solutes differ. It can be run in campaign modes in NFTDC pilot and later on the industry partners customize their individual lines for their feedstock as per gpl loads, more stages and large scale. This is taken up concurrently between industry partner and NFTDC so as to compress time.

In Stage–4, the by-product requirement in clay-based category is a separate and dedicated line which is done partly as pre step (carbon, sulphur (roasting) & iron oxide removal) and finally as post step for fusion /sintering to produce advanced ceramics. In the case of monozite based residues, some small residual quantities of other minerals such as ilmenites and zircon are available to render the entire line techno-economically highly feasible while in the case of clay-based feedstocks, advanced ceramics rather than conventional bricks are necessary. Thus, Stage-4 is customized, dedicated and kept at mine / industry site with large sized plant machinery (one Lakh tons feedstock in the case of clay based feedstock) right from the beginning while at NFTDC, feedstock that is in accordance with batch size is to be kept. This innovative approach has already been kicked in.

Thus, in order to compress time, a more generic and multi feedstock pilot at NFTDC is being established to serve more industry partners and a more customized larger batch size /entry level demo commercial plant for the specific feedstock at industry site for the industry partner are being concurrently done.

6.0 Process Flow Sheets for the two categories developed by NFTDC

6.1 Monozite bearing Residue from Ti/TiO2 Plant

Sl. No	Minerals in residue	Wt %
1	Ilmenite	29.82
	Garnet	7.00
2	Leucoxene	3.31
3	Monazite	22.19
4	Rutile	0.76
5	Zircon	2.90
6	Sillimanite	9.87
7	Kyanite clay	1.06
Total valuable minerals : 43.35%		
Total HMS in residue : 76.90%		
Silica + sand /lighter minerals : 33.35%		

6.1.1 Individual mineral separation from Ti/TiO2 plant residue

The valuable minerals other than monozite at 22% available in the monazite bearing residue are Ilmenite 29.82% + rutile 0.76% + zircon 2.9% & sillimanite 9.87 % altogether, the total valuable minerals are 43.35%. Besides that, other valuable minerals are monazite 22.19% and garnet 7% and leucoxene about 3.31%. By considering all, the total HMS is 76.90%. The other minerals are shown as 33.35%, which are considered as lighter minerals mostly silica /sand.

The separation of individual minerals is based on the individual mineral's physical properties like conductivity, specific magnetic properties, grain size, specific gravity, electrostatic, surface characteristics etc. In addition, separation is also based on its chemical properties like adsorption, adaptability, chemical reactivity etc. The monazite rich residue has about 33% of other lighter minerals which are easily separated.

Properties used in Physical separation (Monozite bearing residue)		
S	**Minerals**	**Properties**
1	Ilmenite	Conductive & magnetic (HTS)
2	Rutile	Conductive & non-magnetic (HTS)
3	Leuoxcence	Conductive & magnetic susceptibility
4	Garnet	Non-conductive moderately magnetic (HTS + WHIMS)

5	Monazite	Nonconductive feebly magnetic (HTS + WHIMS)
6	Sillimanite	Non-conductive & non-magnetic lighter (HTS + MAG + Gravity)
7	Zircon	Non-conductive & non-magnetic, heavier (HTS + WHIMS + Gravity)
8	Kyanite	Non conductive & non magnetic, lighter
General physical properties of each minerals are shown in the table		

6.1.2 Module-1 (mineral separation >> residual ilmenite, zircon, garnet etc separation)

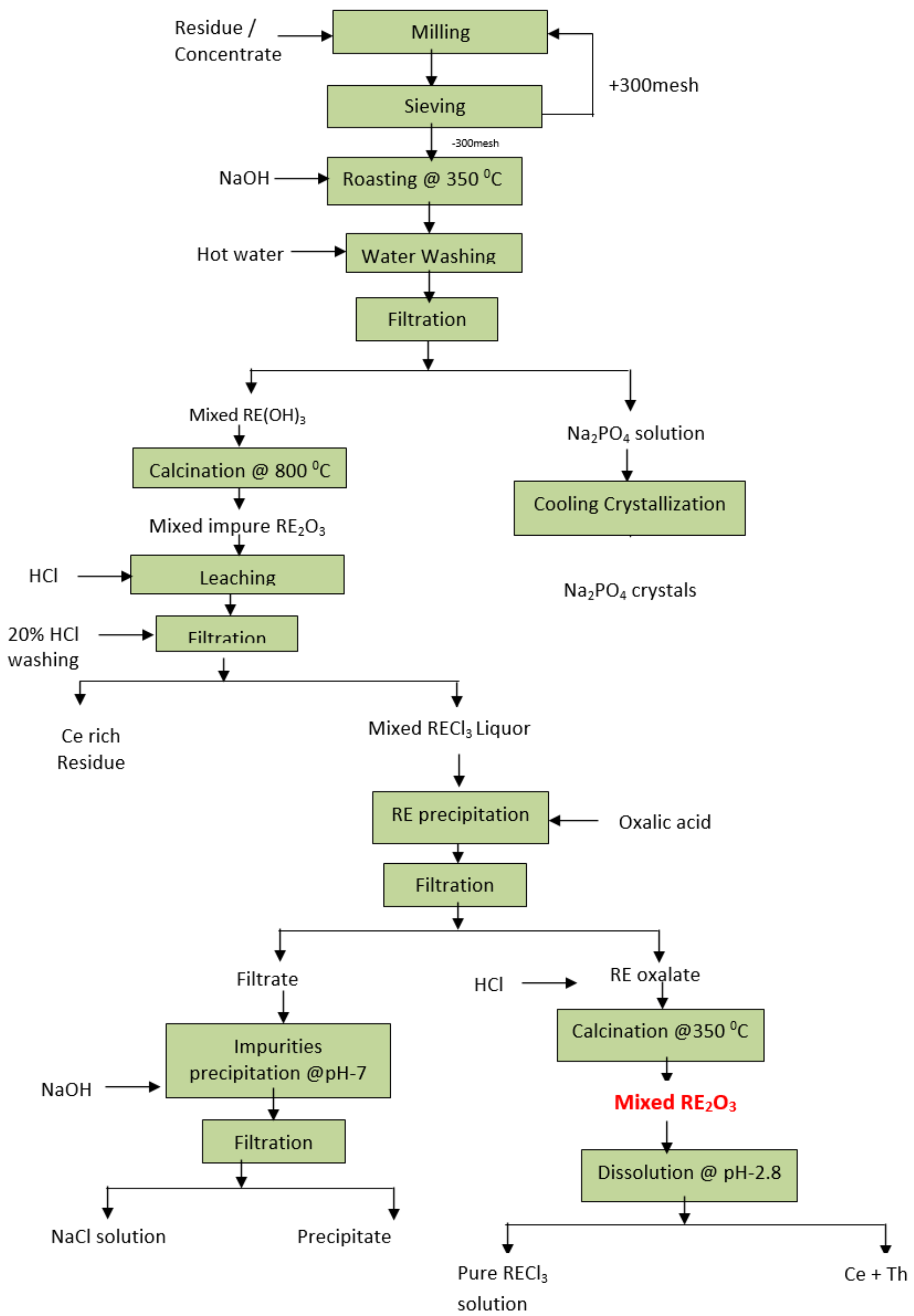
Step -1 (Gravity separation). In the first step, using gravity separation equipments in mini spirals, Hydro-cyclones and by air tabling or combination of these equipments, the unwanted lighter materials (quartz + sand) are separated and pumped back for land filling. Thus, HMS concentrates in residue is enhanced from 77% to 90%, thanks to removal of sand, quartz in a simple step.

Step -2 (HTS). Thereafter, HMS is passed through high tension separator (HTS) to segregate ilmenite (+ small quantity of rutile that is present) as they are conducting materials and others as in monazite, garnet, sillimanite & zircon areas non-conducting.

Step-3 (Magnetic separation). The non conducting portion (monozite +) are treated in the highly intensive magnetic separator to separate monazite + garnet being magnetic from other minerals as in sillimanite & zircon which are being non-magnetic. Later in monazite and garnet are treated in intensive roller magnetic separator by adjusting magnetic power, garnet is separated because it is moderately magnetic and the monazite is also separated since it is feebly/weakly magnetic.

Step-4: Then sillimanite and zircon are separated by treating in floatex, air tabling followed by chemical separation by frothing and addition of soda ash as pH modifier, sodium silicate as depressant and oleic acid as a frother. This is done to recover zircon.

6.1.3 Module – 2 >> Production of Mixed RE Chloride from final monozite residue



6.1.4 Module – 3 SX >> In the NFTDC process, the number of stages gets reduced due to following factors >>

(i) Cerium is removed prior to SX and so in LREs it is only La + Nd +Pr
(ii) Three fractions of La rich, Nd+Pr Rich and HRE rich are first obtained.
(iii) La & Nd are easily separated in another 5 stages each from La rich and Nd+Pr rich extracts.
(iv) Since HRE concentration is less than 5% even in the original TREOs, it has to be collected to get a larger quantity.

NFTDC has experimented with multiple SX chemicals and has optimized it on PC88A followed by TBP.

Comparison of different extraction approaches:

	Depha	**PC88A**	**[PC88A][A336]**	**[Dehpha] [A336]**	**Cynex**
loading capacity	6.3g/1M	5.6g/1M	2.37g/1M	2.67g/1M	NA
Selectivity	Moderate	High	High	High	Low
Crud formation	Yes	No	Yes	Yes	No
Phase Separation	High	High	Low	Low	Moderate
Reusability	Can be reused directly after stripping	Can be reused directly after stripping	Needs regeneration	Needs regeneration	Can be reused directly after stripping
Stripping performance	Good	Moderate to Good	Good	Good	Moderate

Upon actual experiments conducted it became evident that PC88A outperforms other solvents such as DEHPA and binary mixtures (ionic liquids) in terms of selectivity and extraction capacity. Notably, PC88A excels in ease of phase separation and does not necessitate additional processing for regeneration or activation. This advantage over its counterparts offers operational ease and facilitates convenient scale-up.

Optimization experiments conducted on arriving at number of stages in SX.

The purity of Nd+Pr in the first 5-stage itself is more than 95% while recovery is around 60% (increased to 70% with improvements in stripping efficiency) and a repeat over next two 5-stages on the La rich side and change of solvent chemical to TBP results in overall recovery of 87.5% of Nd+Pr. The purity is enhanced to 99% on addition of one more 5-stage in the beginning itself. Thus, two sets of overall 25 stage SX units each (one for La rich side and the other for Nd+Pr rich side) are deemed sufficient, and the same unit can be used for HREs after 30 feed runs in the pilot plant. Even in HREs, we are interested only in Sm, Gd and Dy/Tb, this 20-25 units are adequate. It is not necessary or optimal to remove all REEs as many are less than 2-3 ppm and it results only in large quantities of SX solutions being used. It is important to make sure that stripping efficiency is high as the overall recovery is determined by this step and a loss of 10-15% in stripping can occur if adequate care is not taken.

Stripping, oxalate formation followed by calcination yields separate REOs which are standard unit processes.

6.2 Clay based REEs Feedstock Processing

Clay hosted REEs are more amenable for processing for recovery of REE values. NFTDC has already done extensive investigation of concentrations of REEs in various coal materials supplied by SCCL. REEs are typically at 400 ppm with Nd/Pr at 120-140 ppm and Sc at 50-60 ppm and Dy at 15 ppm. Detailed analysis of available physical beneficiation methods for coal-based materials, it is found that HHS (hydrophobic + hydrophilic) floatation is the most viable option to enhance the concentration to levels of 10X to 20X. The critical path management of this project hinges on this crucial step and hence intensive work is being envisaged. Pre-treatment and multi – lixiviant and multistage leaching is now an established procedure for REE recovery from coal-based materials. This leachate is the common step from multi source REE feed stock. This is followed by SX which is already in the portfolio of expertise in REE separation at NFTDC.

6.2.1 Analysis REE & Availability

Element	**JD-5 DG Clay**	**JD-9** DG Clay	**JD-11** G Clay	**JD-12** Yellow Clay	**R-1A-2** Clay	**R-1S-3** Clay	**JC1-2 DG Shale**	**JC3-2 Coal**
ppm								
La	58	62	55	60	55	68	22	BDL
Ce	108	135	140	121	111	100	147	65
Nd	**97**	**92**	**84**	**107**	**110**	**108**	**92**	**63**
Pr	**16**	**18**	**15**	**16**	**19**	**15**	BDL	BDL
Sm	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Eu	2.2	2.2	1.8	2.6	2.6	1.8	BDL	BDL
Gd	14	15	11	13	15	13	3.6	BDL
Tb	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Dy	**10**	**10.3**	**9.6**	**13**	**14**	**10**	**20**	**9.5**
Ho	**10.1**	**10.5**	**8.7**	**10**	**9**	**10**	BDL	BDL
Er	8.6	9.7	11	10	8	8.7	BDL	BDL
Tm	2.7	2.5	1.9	3	4	2.3	BDL	BDL
Yb	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Lu	0.9	1.2	0.8	1.2	1.5	1.1	BDL	BDL
Sc	**60**	**61**	**60**	**64**	**61**	**57**	**102**	**88**
Sr	**30**	**33**	**29**	**31**	**33**	**29**	**43.5**	33
Total REEs	**418**	**452**	**428**	**452**	**443**	**424**	**430**	**258**

Based on the chemical analysis results, it is evident that clay samples exhibit the highest concentration of Rare Earth Elements (REEs), ranging from 400 to 500 ppm on an as-received basis. This is followed by shale samples with 200–300 ppm, and coal samples with the lowest REE content, between 100–200 ppm.

A significant portion (approximately 50-55%) of the total REE content (of 400 ppm) in these samples is contributed by Nd+Pr (around 120 ppm) Scandium (Sc > 50-60 ppm) and Strontium (Sr-30ppm), HREE (Dy around 10-15ppm). Based on HREE concentrations, clay samples appear to be the most promising material for REE recovery trial.

However, due to the variable carbon content across all sample types, a direct comparison of REE values on an ash basis (i.e., post-carbon removal by ashing) provides a more accurate assessment for downstream physical beneficiation and leaching studies. This also allows for better prediction of recovery efficiencies and material balances. The table below provides a comparative summary of sample characteristics and REE content on an ash basis:

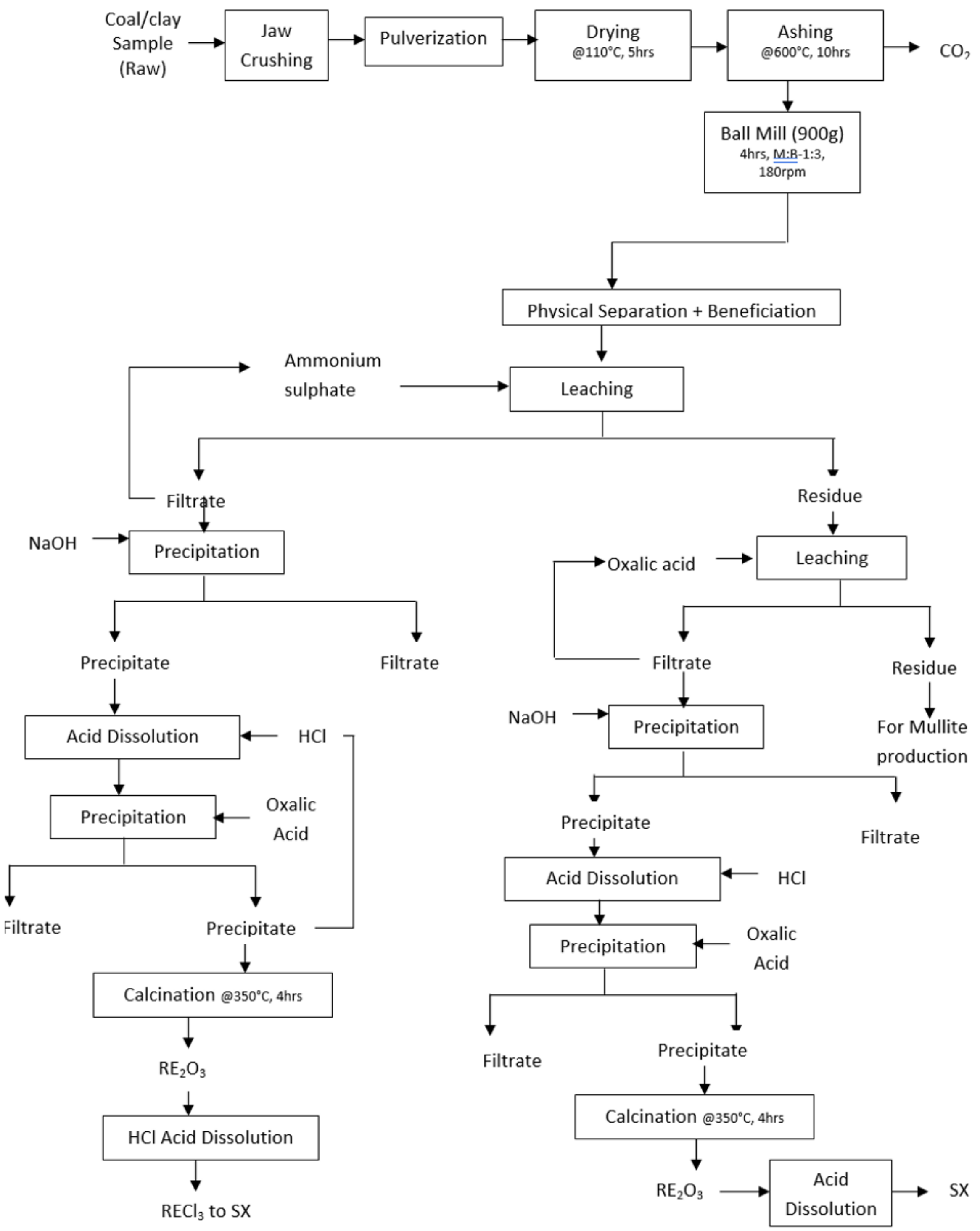
Sample Type	**Input Quantity**	**Avg. Carbon Content**	**Clay Content**	**REE Content in clayey part**	**Nd+Pr | Dy+Tb| Sc | Sr PPM**
Clay	100 g	~20%	~80%	400-500 ppm	**120-130** | 10-12 | **50** | 30
Shale	100 g	~50% (Varies 10–70%)	~50%	300 ppm	90 | 20 | **100** | 45
Coal	100 g	~70%	~30%	250-300 ppm	60 |10| **83** |44

From this data, it can be inferred that **REE content in ashes across all sample types lies in the range of 250 to 500 ppm**, depending on the original sample composition.

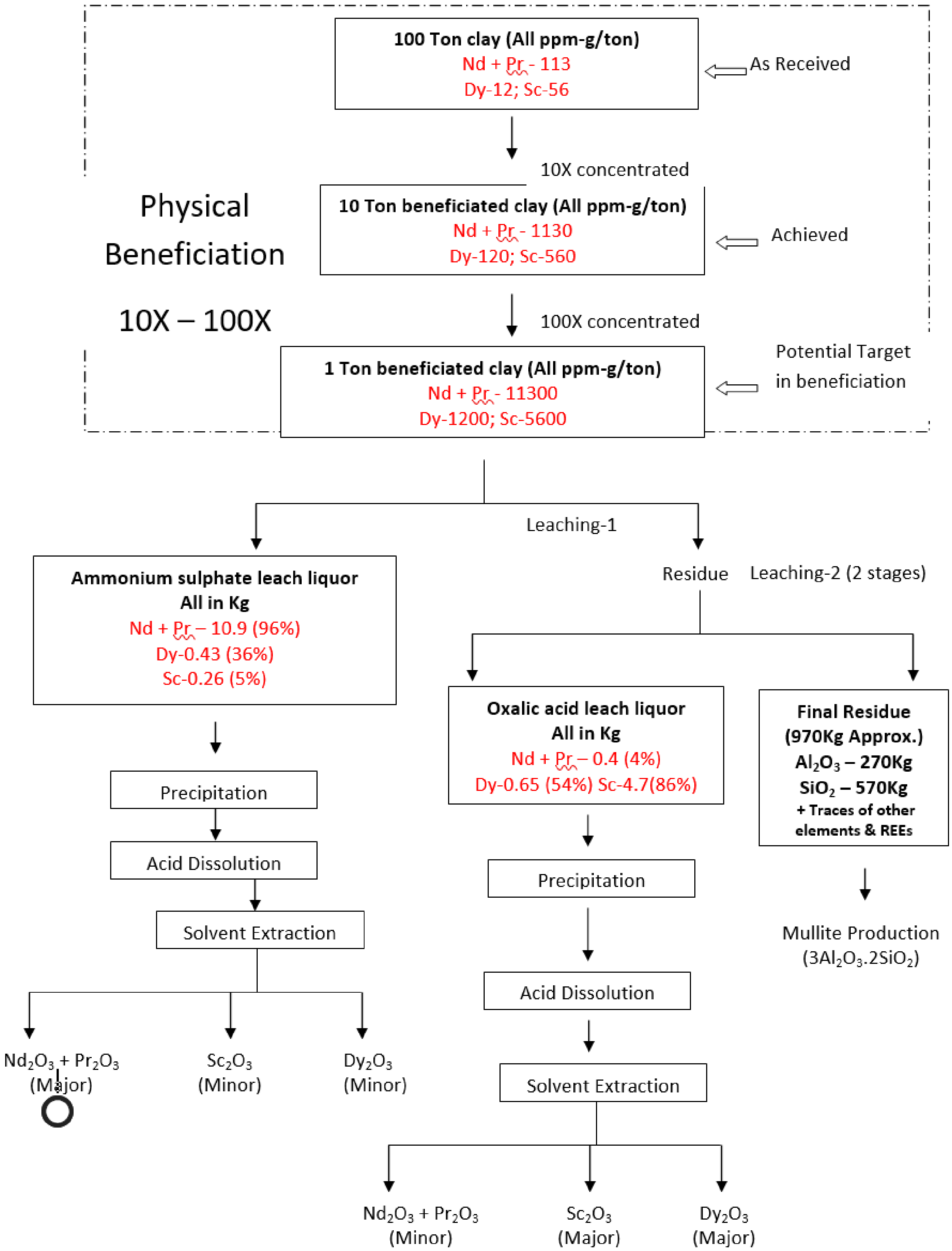
6.2.2 REE Recovery from Clay (NFTDC)

NFTDC developed a process flow sheet for SCCL clay wherein initial communition (50 microns) and roasting/ashing removes C, S and iron oxide is also converted magnetite. A simple high intensity magnetic separator removes iron oxide, and the clay is predominantly alumino silicate. Beneficiation using HHS (hydrophobic – hydrophilic) floatation separation has yielded the highest enrichment levels even going beyond 100 X in our laboratory trials. A REE specific frother was deployed which is our important IP. Thereafter, many many lixiviants were experimented for their efficacy selective digestion of REEs and ammonium sulphate or magnesium sulphate were found to be effective. Another important discovery / finding of NFTDC is use of oxalic acid to selectively remove higher percentage of scandium and dysprosium while ammonium sulphate had a better recovery rate for Nd+Pr. Detailed recovery percentages and processing of 100 tons to obtain beneficiated 10 ton (10X) and 1 ton (100 X) followed by leaching with above two lixiviants in given below.

REEs bearing clay material processing Flow sheet (NFTDC Process)



Mass Balance of 100Ton Clay Input



Solvent Extraction of Clay based REEs (SCCL)

A valuable finding in this work is that subsequent to ammonium sulphate digestion, only Nd, Pr, Sc and Sr were predominantly present in the leached liquor, while La and Ce were BDL were almost nil. This is one of the advantages of ammonium sulphate digestion. Further separation by SX has now become much simpler compared to monozite residue-based liquor. The drawback is that tenor is lower and larger quantities of input of staring materials is needed for physical beneficiation. Thus 100 tons is taken to eventually achieve 1 ton of highly beneficiated clay.

6.2.3 Waste Utilization (Mullite production from beneficiated clay and final residue):

The final residue remaining after the leaching and extraction of rare earth elements (REEs) can be considered highly purified clay without iron and other oxide impurities. The chemical composition After leaching, primarily REEs along with only a minimal amount of the matrix are dissolved in the acidic lixiviant. This process flow sheet offers the advantage of selectively dissolving the target elements without significant dissolution of the matrix or inducing any major chemical changes in the residue. The beneficiated clay and final residue obtained after REE recovery was subsequently analysed to assess its grade through chemical testing. (* carbon + Sulphur forms the remaining 15%-20% approx) The final clay residue is meta – kaolin type and it is ideally suited for engineered ceramics manufacture.

Elements	Wt%	Wt% as Oxides
Mg	0.30	
Al	14.15	**26.7**
Si	26.28	**56.2**
S	0.30	
K	1.24	
Ca	0.42	
Ti	1.52	
Fe	1.83	**2.6**
Cu	2.09	
Mg + Ca		1
$SiO_2 + Al_2O_3 + Fe_2O_3$		**~85% (*)**
After iron oxide removal		**Meta – kaolin clay of only SiO2 & Al2O#**

Al2O3-SiO2 based ceramics are manufactured in a wide range of compositions, the most notable one being the alumina rich mullite, the composition of which is given below.

Even if Fe2O3 is not removed, it serves as a sintering aid along with traces of other oxides. Pure mullite is 72/28 composition in terms of Al2O3/SiO2 and it is made by fusion.

Below is the typical target composition of Mullite ($3Al_2O_3.2SiO_2$) phase

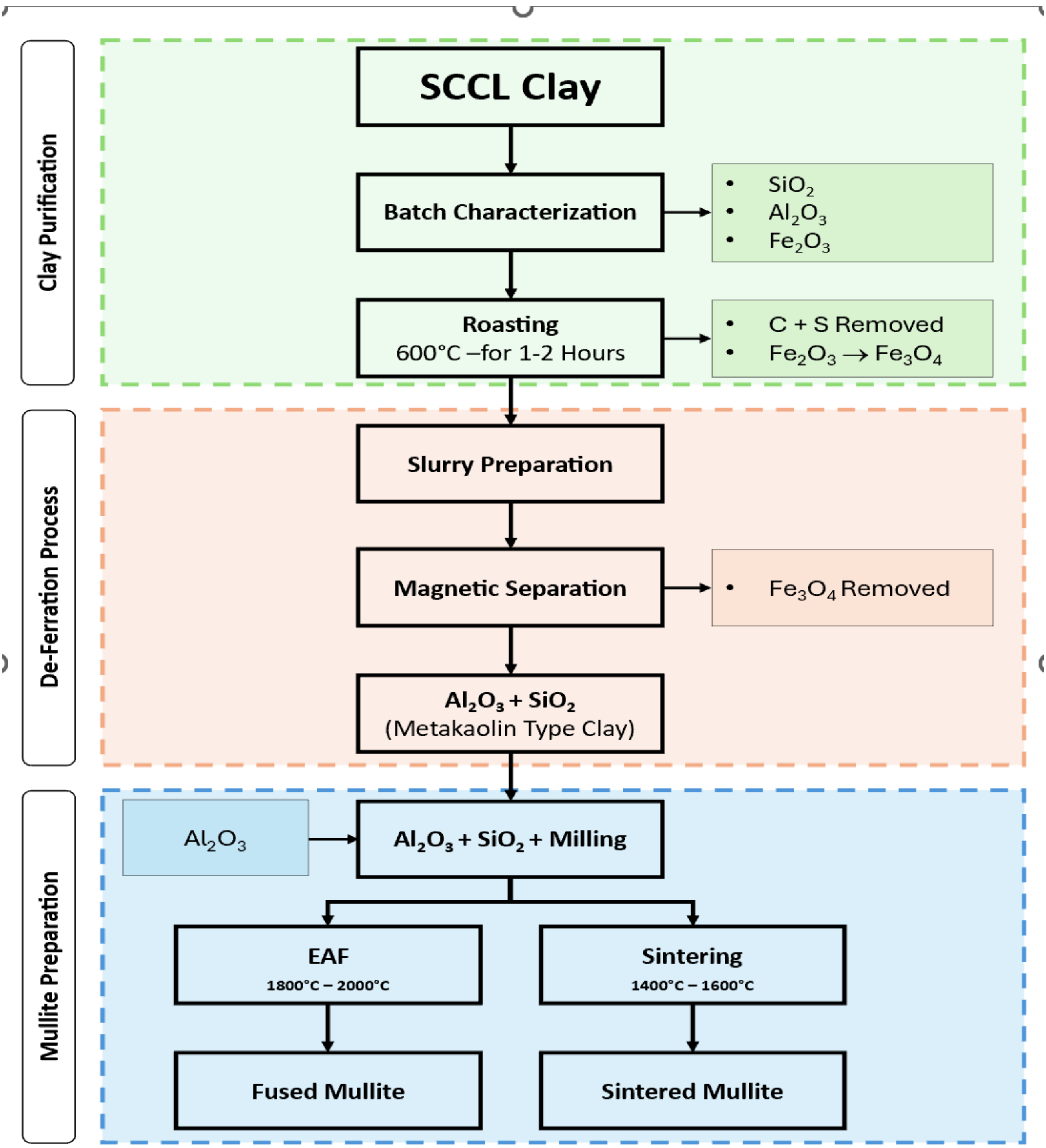
Material	Target Composition%
Al2O3	70-77
SiO2	22-29
Fe2O3	0.3% Max
K2O + Na2O	0.4% Max
CaO +MgO	0.4% Max

Required alumina additions to produce FUSED Mullite (3 Al2O3 .2 SiO2) from final residue

Basis - 1Ton Input (Processed Residue) + 1.4 Ton of ayer alumina & 2.3Ton output (Mullite)			
Material	**Mullite composition (Kg)**	**Available in clay Residue (Kg)**	**Top-up to be added (Kg)**
Al_2O_3	730	260	(730-260) + [(560-240) x (73/24)] = 1440
SiO_2	240	560	0
Fe_2O_3	3 Max	20 (removed in beneficiation)	0
$K_2O + Na_2O$	4 Max	-	0
CaO +MgO	4 Max	-	0

Beneficiation of SCCL Clay and waste to Wealth (kaolin clay and advanced mullite ceramics)

Clay is beneficiated by simple means of roasting which removes C, S and conversion of Fe2O3 to Fe3O4. Thereafter, a simple magnetic separation purifies the clay by removing iron oxides which increases its whiteness. NFTDC conducted a series of experiments on conversion of SCCL clay after removal of carbon, sulphur and iron oxide into various mullite compositions. The synthesis is excellent with phase purity and compositional range attained. It is planned to process nearly 1 ton of material into mullite ceramics in the next 2 months. A full-fledged plant for mullite is being designed for establishment at SCCL site in industrial scale, up to 70-77% Alumina mullite has been made in EAF equivalent arc melting system at 2000 C and also by sintering at 1600C


Clay Purification
SCCL Clay
Batch Characterization
SiO2
Al2O3
Fe2O3
Roasting
600°C –for 1-2 Hours
C + S Removed
Fe2O3 → Fe3O4
De-Ferration Process
Slurry Preparation
Magnetic Separation
Fe3O4 Removed
Al2O3 + SiO2
(Metakaolin Type Clay)
Mullite Preparation
Al2O3
Al2O3 + SiO2 + Milling
EAF
1800°C – 2000°C
Sintering
1400°C – 1600°C
Fused Mullite
Sintered Mullite

6.2.4 Potential By-Products from SCCL Clay

The following are the potential by-products from SCCL – clay

- Simple beneficiation to remove C, S and iron oxide gives a meta–kaolin type of clay which becomes raw materials for production of porcelain.
- Addition of Bayer – alumina and sintering at T = 1600 C give multiple grades of mullite ceramic
- Complete conversion of high alumina 72/28 to 77/23 mullite in EAF commands the highest price in mullite products.

Total world Production of kaolin type clay was around 30 million tons in 2022. A fraction of it at say 2-3 MMTPA can come from these clay raw materials after beneficiation if SCCL and other potential coal companies take up the challenge

6.3 Techno-economics of Waste utilization into kaolin & Advanced Mullite Ceramic

Notes: Basis – 1Ton Input of final residue for mullite production.

- Mullite yield:
  From 1 ton of final alumino – silicate clay residue, a total of 2.3 tons of mullite powder will be produced (process loss (2.44 >> 2.3 tons) and 10% yield loss are assumed) with addition of fresh Bayer alumina for complete conversion.
- Market rate of mullite powder: Rs.150 per kg (considered lowest price for high alumina content fused mullite/sintered mullite)
- Total mullite value (at 90% recovery efficiency): 2,300 kg × 0.9 × Rs.150/kg = Rs.3,00,000
- Cost of top-up alumina: Reqd alumina = 1,440 kg; Cost = 1,440 kg × Rs.80/kg = Rs.1,15,000
- Net value addition for mullite production waste alumino – silicate clay. (SCCL)
  Rs.300,000 – Rs.1,15,000 = Rs.1,85,000/Ton of residue.

Even, rest of 80 – 90 tons (C, S, iron oxide removed materials) from beneficiation circuit (100 Tons input) still has value and each ton of it can give direct sale value. The following are two options.

Option-1: Left over clay after beneficiation (removal of Fe_2O_3) itself commands a good price, the typical price being Rs 60, 000 /ton and nearly Rs 50 Lakhs per 100-ton feed is obtained.

Option-2: Convert beneficiated clay part into Mullite, with net value addition of Rs 1,85, 000 /ton x 80 tons gives approx. 150 Lakhs. Carbon, sulphur and iron oxide removal is the key. Assuming conversion costs at Rs 1 lakh/ton due to high energy intensity of the process, a net margin of Rs 85, 000/ton can be envisaged. Thus, value addition and net margins are significant to give a prima facie techno-economic feasibility for the entire process.

It is also advisable to produce high alumina mullite of 77wt% Al_2O_3 which commands the highest price for mullite. Thus, even if the cost of production of mullite from waste clay is around Rs 1 Lakh per ton, it still gives high net margin. Fused mullite (1800 – 2000 C) produced by EAF and high T sintering (1600-1800 C) are the most sought after mullite products. Conventional production of fused mullite is by direct mixing and melting in EAF of bayer grade alumina and pure quartz in the required weight ratios or by sintering the finely ground compacts of alumina and pure quartz. The clay residue brings in both alumina and silica and the required alumina is topped up. Thus, the waste is valorised significantly while also pulling out REEs. In addition, if sintering aids such as Fe_2O_3, TiO_2 etc are considered at 1-wt%, they are already available.

In effect, it is the clay and mullite ceramics that makes the entire plant viable even without REEs extraction. REE extraction can therefore be cross – subsidized by sale of clay and / or mullite ceramics.

7.0 Implementation Strategies & Preparedness

7.1 Implementation is done in terms of priorities and appropriate specific tie-ups for source as described elaborately in section 6.

- **(i)** domestic monozite residue from Titanium plant (KMML, AP) MIDWEST + KMML
- **(ii)** clayey materials from SCCL, CIL and imported ionic clay (calcined); **c**oal waste (clayey seams which have been proven by NFTDC to contain 150 ppm MREOs, 50 PPM scandium and 15 ppm Dysprosium.).
- **(iii)** (100 TPA) called RE sludge (in-house) and rejected magnets
- Tertiary source >> (iii) In process RE waste from the **REPM** plant; Used RE magnets from hard disks and e-waste (already in NFTDC)
  These raw materials are already tied up.

- **(iv)** Sn – slag tailings (medium tenor (1000 ppm of MREOs) from Brazil
- **(v)** Phospo-gypsum >> will be taken up only if sources with MREOs cross the threshold of Nd/Pr, and / or Dy/Tb of at least 250 ppm.

First two resources, namely monozite bearing residue and clayey materials are taken up on priority followed by RE sludge waste. Others as they arrive, dedicated campaigns will be run on for example Sn – slag REE bearing resource will be taken up. Only those sources that cross the MORE threshold (such as the ones given above) will be taken in to pilot campaigns.

7.2 Preparedness:

NFTDC has been set up with a mandate of TRL 7-8 level pilots as deliverables from its inception days in 1990s for advanced materials. It is in this background, even the RE magnet plant got done in late 1990s to early 2000s. The organizational form and structure and mission mode of working with a systems approach has been the hall mark of NFTDC's activities.

In this specific case of REE oxide materials, it has been many prior activities were front loaded to enable this proposal as well as its speedy implementation. They are

(i) Extensive analysis of samples over the past 18 months from India and Abroad and freezing of two major categories of feedstock for next steps, namely (i) monozite bearing residue from Ti/TiO2 plants and (ii) REE bearing clay from coal seams.

(ii) Lab scale studies were completed and potential flow sheets developed, particularly with emphasis on MREOs (magnetic rare earth oxide content in feedstock).

(iii) Industry partners in NFTDC CoE were encouraged and enabled for the two categories, not just with MoUs, but with important tie-ups for setting up demonstration commercial plants on a concurrent mode. Towards this end, both Ti/TiO2 bearing feed and clay feedstock were taken up by Midwest & KMML in the case of former and SCCL and CIL in the case of latter.

(iv) Generic pilot at 100 kg (min) batch at NFTDC for handling multiple feedstock of present and future and concurrent demonstration plant (1–2-ton batch for Ti/TiO2 and 1 lakh ton for clay feedstock) are already frozen. Major core competence of NFTDC in materials + Process Equipment designs and fabrication have been deployed to bring in the multi – disciplinary work break down and execution methodologies well known and practised by NFTDC.

(v) NFTDC has started all the procurement actions that can be done prior to PO placement for equipments so as to realize line in 12 months or less. NFTDC technology bays dedicated to critical materials under CoE already put in place augmenting existing technology bays. As NFTDC has a continuous project associateship programme, induction of project staff at JRF< SRG<RA levels in multiple disciplines is routinely done.

(vi) Project co-funding by the industry partners for NFTDC pilot tied up with agreements + PO put in place.

(vii) Higher management decisions for demo commercial plant at the first two sites done and the implementation runs parallel so as to compress time for commercialization. Many past endeavours have given the necessary SOPs for setting up both pilots at NFTDC and first demo commercial plants by NFTDC and industry partner. Here the industry partners are on-boarded with specific plant capacity level targets on day one and they have also moved on ground to meet the national emergency in REE oxide supply augmentation.

7.3 Capabilities and Capacity of NFTDC – Salient Past performance at TRL-7-9 level plants

NFTDC Capability Statement

Summary

NFTDC is a premier R&D institution specializing in translational research across TRL 3–8 spectrum. It has demonstrated unmatched capability in designing, developing, and commissioning pilot plants for advanced technologies and transitioning them to mature production. Its expertise spans aerospace, defense, space, biomedical, energy systems, and resource recovery.

NFTDC's readiness to establish high-technology pilot manufacturing lines is evidenced by recent (2012 – 22) successful execution of TRL-7 pilot plants for Urban Mining of Li-ion batteries, recovery of precious metals from BGML tailings, hydrogen energy systems, and advanced copper alloy facilities for ISRO's cryogenic programs.

NFTDC REPM pilot plant for making RE magnets has been operational since 1998 and has been serving important national needs. Presently, end to end (oxide to Magnet) commercial plant of 500 TPA put up by the industry partner.

Core Strengths

- End-to-End Capability: Concept design to commercialization.
- Materials + Design + Electronics >> Multidisciplinary Expertise: Advanced materials, electrochemistry, mechanical systems, electronics, and biomedical engineering; System Development & Integration
- Materials + Process + Product + Plant >> Systems Approach and high TRL deliverables
- Parallel Processing & Concurrent Engineering for time and budget compression
- Infrastructure: Continuously developing technical facilities at both lab and pilot scale.
- Track Record: Execution of complex projects and pilot production plants for ISRO, DRDO, DST, HPCL, BrahMos Aerospace, and ITER-India.

Established Pilot Plants (TRL-7) and entry level commercial plants (2012 – 24)

1. Urban Mining of Li-ion Batteries
- Pilot plant Capacity: 2 TPD spent batteries → 1 TPD black mass.
- Process: Mechanical shredding, hydrometallurgical leaching, solvent extraction.
- Outputs: High-purity Lithium, Cobalt, Nickel, and Manganese compounds.
- Features: Low chemical consumption, zero effluent discharge, process intensification.

Current Status >> Commercial Plant of 10 000 TPA plant put up Industry Partner.

2. Recovery of Gold & Precious Metals from BGML Tailings
- Process: Non-cyanide chloride-hypochloride leaching.
- Discovered Pd and Rh in addition to gold and hence enhanced the asset value
- Pilot Scale: 500 kg/batch; processed 10 tons of material and proved the non-cyanide
- process for concurrent extraction of Au, Pd and Rh.
- Outputs: Au, Pd, Rh recovery of 1.5–2 ppm vs original estimate of only 0.5 ppm extractable Au
- on time completion of pilot plant in 2021-22; the asset value of 32 Million tons was increased from mere Rs 4500 Cr to 24,000 Cr thanks to this effort; presently it now stands around Rs 72, 000 Cr (2025)

- First TEFR and BEP done by NFTDC and later on expanded by EIL as TEFR for 4 MMTA industrial plant and MoM is putting forth auction plan in the coming months.

3. Cobalt Recovery & Biomedical Alloy Development
- Scope: Extraction of Co from scrap → Alloy melting → Implant manufacturing.
- Innovation: Proprietary ceramic crucible for melting reactive alloys at 2000°C.
- Design of advanced electrolysis cell with differential pH control.
- vacuum grade alloys produced;

4. Recovery of Mo & Ni from Spent Catalyst
- Partner: HPCL.
- Pilot Scale: 40 kg/batch using ultrasonic/microwave-assisted leaching.
- Output: >90% Mo recovery; Ni recovery under optimization.
- HPCL taking up next steps for in-house plant

5. Biomedical Implants- Total Knee Prosthesis (TKP2.4)
- Status: Pilot production and clinical trials completed (~ 75 Implantations + Follow up)
- Next Step: ISO 13485 certification + manufacturing license.

6. Cryoengine Materials >> CuCrZrTi Alloy Plates & OFE Copper Pilot Plant
- Dedicated facilities for melting, hot rolling, in-line furnaces, straightener, plano-milling, QC labs, and TMP optimization.
- OFE Cu & Cu Alloy pilot plant at 100 TPA for national strategic missions.
- Strategic Impact: Indigenous supply for ISRO's semi-cryo and cryo engine programs.

Other High-Technology Products Developed which are progressing to pilot and entry level commercial plants

• Aerospace & Defense: High-speed alternators (AMOGH), motors for LCA fuel pumps, RVDTs, 75kVA generator for AMCA >> Limited Series Production started 2023 onwards

• Biomedical: Indigenous knee prosthesis, cobalt-based implant alloys >> in clinical trial >> surgeries + 2 year follow – up completed. Entering Production with manufacturing license.

Energy Systems: SOFC systems, hydrogen storage, sorption cooling, 50kW alkaline water electrolyzer >> materials to product development leading to Limited Series Production

• Advanced Materials: Tungsten alloys for BrahMos (long term partnership)

Commercial Plant 500 TPA Rare earth magnets (NdFeB) 2024-26

Strategic Importance

NFTDC's initiatives align with India's strategic goals in resource security, clean energy, aerospace, and healthcare. Indigenous development reduces import dependency and strengthens national self-reliance.

NFTDC has been safeguarding and maintaining the end to end technology for REPM manufacture since 1998 and is presently directing efforts for capacity building to 500 – 5000 TPA with industry partnership.

8.0 Activity vs Timelines

- As already been outlined, the aim of this proposal is twofold – one to establish the physical plant and machinery to obtain manufacturing lines and the second to run campaigns in larger batches of 100 kg plus for multiple feed stocks in campaign modes with aim of optimizing each of the feed in terms of process parameters, yield, recovery at higher scale compared to lab experiments.

- NFTDC pilot lines are done in a generic mode to handle multiple feedstocks and clients at TRL7-8. This activity is funded by scheme with industry co-funding.

- Concurrently, at industry sites, viz KMML and SCCL, a demonstration scale commercial plant is being implemented. This demonstration plants are specific to that feed, and they are at TRL 8-9. This activity is entirely done by industry with NFTDC support on the technology front.

	Activity	**Timeline**	**Remarks**
1	Preparation of NFTDC Technology Bays	To to 6 months	Technology Bay – 7 created for CoE on Critical Materials to house all pilots.
2	Raw Materials Feed stock	To	Two main category sources already. 10 tons in place for clay and much larger quantity segregated at KMML for movement.
3	Project Staff	To – 6 months	50% of JRF &SRF are already in place in NFTDC project associateship program. Rest to be in by Jan 2026.
4	NFTDC – PILOT Capital Equipments procurement	To to 9 months	All equipments identified; prior to PO done. Sizing is done. Generic line to run campaigns of different feeds.
5	Installation & Commissioning	12 - 15 months	Site preparation ready. Mechanical and electrical teams in place
6	Experimental runs on 2 sources.	16- 24 months	100 kg / batch experiments Process optimization
7	3rd source feedstock Tertiary RE magnet slurry & EOL magnets	6th Month onwards	In – house magnetic materials slurry available and it is plugged at appropriate gap periods in pilot plant; Nearly 3 tons feed in place.
8	Documentation	18-24 months	Continuous activity
9	IP	9th month -	
10	Industry site preparation	Already started	

Outcomes, Potential Impact and Deliverables

- The major outcome of this endeavour is translational R & D that pushes the Technology Readiness Levels to pilot production and higher at TRL 7-9 with specific emphasis on Rare Earth containing feed stock from primary, secondary and tertiary sources.

- Secondly, the separation processes are to be optimized for specific feedstock in detail with regard to minimization of steps, particularly in solvent extraction segment.

- Impact of this endeavour will serve the national need for development of multiple commercial scale RE oxide production points in the country as well as serve companies in their off-take / asset acquisitions abroad. Hence, concurrently two demo plants at industry sites are concurrently taken up.

- Furthermore, as the scale – up is in modular form, many such entities are possible based even on multiple feed stocks and other companies can also be enabled.

- The deliverables are
    - Pilot Line with all separation processes in modular format (100 – 250 kg batch).
    - Process optimization for different feed stocks at pilot scale at NFTDC and tonnage scale at Industry site.
    - Interact with potential companies with their input feedstock and take in their raw materials and process the materials once the pilot plant is set up and running. Important clients such as KMML, Midwest, SCCL are already tied-up and industry sites being readied.
    - Skill development programme can be dovetailed to this pilot plant as per the norms of the skilling programme in NCMM.

9. Budget

OVERALL BUDGET

	OVERALL BUDGET (Rs, Lakhs)			
		MoM	Industry	
	Cost Head	**Amount**		**Remarks**
1	Equipment	991	289	As per enclosed list
2	Raw Materials/Feed Stock		20	Imported only as and when a specific source is available
	Sub total -1	**991**		
3	Consumables	115		Chemicals, Gases, Refractories, Spares, Standards & Analysis
4	Human Resource	96	72	6-PAs (3L X 2) ; 6-SPA (5L X 2); Other Operation by Industry
5	Other Cost	150		Auxialires + Allied System; Electrical, Water, Air, Cooling Towers; AMCs; Structural Fabrication - Erection ; Fabrication & Job Work; ETP
6	Contingency	14		@ 1% appx
7	Institute Over Head	135		@ 10% appx
	Sub total -2	**510**		
	TOTAL	**1501**		
	Industry Contribution		381	@ 25%
	GRAND TOTAL		1882	*Industry contribution @ 10%=Rs 188L>> Rs 160L already tied up Another 10% will be in.*

Equipment List with Justification (Rs, Lakhs)

	Equipment Description	Estimate	Industry	Justification
A	**Mineral Beneficiation Equipment**			
1	Crushers & Pulvelizers	20		Crushers (jaw, cone, impact) and mills (rod, ball, or roller) are essential as first-stage preparation to liberate rare earth minerals from gangue by reducing particle size. For clays, beach sands, and coal byproducts, complete mineral liberation is crucial because rare earth minerals are often extremely fine-grained and intimately associated with other minerals. Proper size reduction enhances downstream separation efficiency
2	Classifiers / Hydro Cylones (wet); Air Classifiers (Dry)	8		Screening and De-sliming
3	Floatex Density Separator	25		Flotation is widely applied for rare earth recovery from ores where gravity or magnetic separation cannot achieve effective concentration. By exploiting differences in surface chemistry, flotation cells are able to selectively separate rare earth-bearing minerals from gangue minerals in clays, beach sands, and coal byproducts. The process is particularly crucial for low-grade ores where fine particle separation is required.
4	Spiral + Allied Setup	60		**Spiral concentrators** are justified in REE recovery from coal waste because they provide an efficient, low-cost, and continuous method to separate heavy minerals based on density and flowing-film behavior in the 0.15–2 mm size range. After desliming and pre-concentration (e.g., via FDS), spirals sharply separate light gangue (coal, shale, quartz) from moderate-to-high density REE minerals (monazite, xenotime, zircon, ilmenite) under laminar flow without the need for chemicals.
5	Wilfley Table/ Shaking Tables	35		It provides very high-resolution gravity separation for the 75–500 µm size fraction, delivering cleaner heavy-mineral concentrates that significantly reduce the load on downstream magnetic and electrostatic stages.
6	Multi Gravity Separator (MGS)	50		MGS uses a combination of **centrifugal force, shaking motion, and thin-film separation** to dramatically improve the recovery of these weakly responding fine particles. It is especially effective for concentrating **paramagnetic or heavy**

	Equipment Description	Estimate	Industry	Justification
				mineral fractions prior to WHIMS/HTS or as a scavenger step following spiral circuits.
7	Falcon Separators	20		Highly effective in REE beneficiation because they generate very high centrifugal forces (up to 300 G), enabling efficient separation of fine and ultrafine REE-bearing minerals that have limited settling velocity in conventional gravity devices. Incorporating Falcon concentrators in the circuit can significantly boost overall recovery, reduce the load on WHIMS/HTS units, and improve the grade of intermediate concentrates.
8	Magnetic Separators (Drum & WHIMS)	60		Magnetic separation (LIMS/HIMS/WHIMS) targets **iron-rich and paramagnetic REE carriers** such as monazite, xenotime, and Fe-oxide–associated REE phases, which cannot be segregated by density alone.
9	High tension Separator	70		High-tension electrostatic separator exploits **surface conductivity differences**, isolating non-conductive rare earth phosphates and silicates from conductive residual minerals like ilmenite or pyrite.
10	ESP	15		
11	Ultrastat Plate	15		
12	Flotation Cells	50		Flotation is widely applied for rare earth recovery from ores where gravity or magnetic separation cannot achieve effective concentration. By exploiting differences in surface chemistry, flotation cells are able to selectively separate rare earth-bearing minerals from gangue minerals in clays, beach sands, and coal byproducts. The process is particularly crucial for low-grade ores where fine particle separation is required.
13	Miscelleaneous Gap Eqpt		80	Any Gap equipment
	Subtotal	**428**		
B	**Digestion & Extraction plant**			
1	Reactors and Filters (3-5kL)	25	15	Equipment required to extract the REEs from concentrate obtained from Beneficiation
2	Mini Steam boilers ~ 850kg/hr	17		
3	Glass Lined reactors ~ 650Ltr	15		
4	Solvent Extraction Systems 25 stage (2 sets)	80	80	Solvent extraction (SX) units are critically important in the separation and recovery of Rare Earth Elements (REEs) because they provide the only practical, industrially proven method for achieving the extremely

	Equipment Description	Estimate	Industry	Justification
				high selectivity and purity required to split individual REEs from a mixed concentrate.
5	Instrumentation & DAQ, and Electricals, Sensors	25		pH, ORP, TC, P, Flow meters,
6	Pumps (Slurry) & Allied Piping	18		Required for the slurry transport
	Sub total	**180**		
C	**Testing & Characterization Eqpts**			
1	XRD - (with High T attachment)	130	100	Required for detailed Characterisation in stage-wise process testing.
2	XRF (Hand-held / Table Top)	28	14	Rapid In-Process Control / Sorting ; This is essential for Process control and quick reporting on output and performance of beneficiation equipment
3	ICP - OES	110		Essential Analytical Equipment
4	MW digester for sample preparation	40		Essential Analytical Equipment; For efficient dissolution
5	Magnetic Property Measurements; Hard Magnetic B-H loop tracer with High T attachment; Soft - Magnetic measurements	75		Meant for assessemtn of feed-stock & final product also
	Subtotal	**383**		
	TOTAL (Rs, Lakhs)	**991**	**289**	* Rs 160L already finalized & Rs 80L rcvd as 1st Tranche (SCCL)

Details of Other cost (item – 5)

Sl#	Other Cost	Amount (Rs, Lakhs)
1	Auxiliaries - Generator Backup Gas bank site preparation; DM water facility	12
2	Electrical Related (Cables, DB, Controls etc)	14
3	Water Circulation Systems/ Pumps etc	9
4	Air Compressor, Dryer, Dehumidifier	11
5	Cooling Towers	7
6	AMCs of Eqpt (~ 3 years) |	18
7	Structural Fabrication - Erection	28
8	Fabrication & Job Work - Customized Requirements on equipment line	21
9	Effluent Treatment Plant	20
10	Other Miscellaneous Cost	10
	TOTAL	**150**

10. Conclusions

a. The envisaged pilot line for separation of minerals/ores/concentrates/residues containing REEs is being taken up on a fast-track mission mode.
b. The pilot plant line will thereafter be managed on a self-financing mode by NFTDC and serve the industry and national needs as per requirement.
c. NFTDC will use this plant to continue to produce REE materials so as to keep the knowledge capability alive in a pilot level so as to serve capacity building in commercial scale by industry. In addition, NFTDC will keep it operational particularly for HREEs such as Dy and Tb as the scale of requirement for these two are closer to NFTDC pilot itself.
d. The pilot plant will also serve for skill development under NCMM.
e. Concurrently, the industry partners in NFTDC CoE shall set up demonstration scale commercial facility and the NFTDC pilot will serve TRL-7 scale while the industry site plants serve TRL 8-9 levels. NFTDC is the knowledge partner for these endeavours.

For and Behalf of NFTDC

(Dr K Balasubramanian)
Director

Ministry of Mines

Pilot Projects for Recovery of Critical Minerals from overburdens / tailings / fly ash / red mud etc.

Technical Experts Cost Committee (TEC)

Minutes of TEC Meeting held on 26-11-2025

1. The Ministry of Mines, through NMEDT, has released the "***Guidelines for Pilot Projects for Recovery of Critical Minerals from Overburdens, Tailings, Fly Ash, Red Mud, etc.***", in alignment with the National Critical Minerals Mission (NCMM). These guidelines aim to enhance domestic availability of critical minerals by supporting pilot-scale mineral recovery initiatives (OM F. No. 122/1/2025-NMEDT/515 dated 14.11.2025).
2. In accordance with these guidelines, the Ministry invited applications from the designated Centre of Excellence (CoE) for setting up pilot projects in this domain.
3. JNARDDC, Nagpur—an autonomous body under the Ministry of Mines—was designated as the Project Management Agency (PMA) for the scheme. Under this mandate, a proposal was received from the Non-Ferrous Technology Development Centre (NFTDC), a designated CoE hub, titled:

"**Establishment of Pilot Line for Rare Earth Mineral(s) Separation from Multiple Feedstocks**"

4. To undertake technical evaluation of the proposal, the Ministry constituted a Technical Experts Committee (TEC). Following receipt of nominations from all organizations, the TEC (list at Annexure 1) convened via video conference on 26.11.2025, organized by JNARDDC in its capacity as PMA.
5. The proposal submitted by NFTDC was reviewed in detail by the TEC, covering technical feasibility, scope of work, proposed infrastructure, budgetary requirements, and alignment with NCMM objectives. Based on the deliberations, the TEC recommended the proposal for consideration by the Project Sanctioning Committee (PSC) for further necessary action.

Ministry of Mines

Pilot Projects for Recovery of Critical Minerals from overburdens / tailings / fly ash / red mud etc.

Technical Experts Cost Committee (TEC)

Details of Recommended Proposals for Consideration to PSC

<table>
<tr><td>Proposal Title</td><td colspan="4">Establishment of Pilot Line for Rare Earth Mineral(s) Separation from Multiple feedstocks</td></tr>
<tr><td>Institute Name</td><td colspan="4">Nonferrous Materials Technology Development Centre (NFTDC), Hyderabad, Telangana</td></tr>
<tr><td>Category</td><td colspan="4">Centre of Excellence - Hub</td></tr>
<tr><td>Project Lead</td><td colspan="4">Dr K Balasubramanian</td></tr>
<tr><td>Duration of project</td><td colspan="4">24 months</td></tr>
<tr><td rowspan="2">Objectives & Deliverables</td><td colspan="2">Objectives</td><td colspan="2">Deliverables</td></tr>
<tr><td colspan="2">• Strengthen NFTDC's beneficiation and solvent-extraction (SX) capabilities for recovery of major magnetic rare earth oxides (Nd, Pr, Dy, Tb, Sm+Gd) and integration with the REPM manufacturing line.
• Establish a pilot plant (100 kg batch input) for processing multiple feedstocks containing REE processing, covering physical separation, beneficiation, SX, and oxide production.
• Optimise process parameters for different feedstocks at pilot scale and ensure full feedstock utilisation with value-added by-products.</td><td colspan="2">• Establishment of a modular Pilot Line (100–250 kg batch capacity) covering all separation and processing steps for REE recovery.
• Pilot-scale process optimisation for multiple feedstocks at NFTDC, and scale-up validation at partnering industry sites.
• Engagement with prospective industry partners (e.g., KMML, Midwest, SCCL) for processing their feedstocks once the pilot plant becomes operational.
• Provision for integrating a skill-development module.</td></tr>
<tr><td>Industry Partners</td><td colspan="4">Midwest, Kerala Minerals and Metals Ltd (KMML), SCCL</td></tr>
<tr><td>Proposed Budget (in ₹ Lakhs)</td><td>Total budget: 1882</td><td colspan="2">Industry Contribution : 381 (20%)</td><td>MoM Grant: 1501</td></tr>
<tr><td>Observation / Remarks:</td><td colspan="4">• The proposed pilot project is well-conceived, with a strong technical foundation.
• The research team possesses significant domain expertise and has demonstrated a proven track record in executing similar projects.
• The Committee appreciates the Principal Investigator's emphasis on generating higher-value products from process rejects, rather than limiting utilisation to low-end applications.
• The committee suggests that NFTDC may consider engaging a specialised group to explore innovative, high-value conversion pathways for waste streams.
• As the proposal already includes an interested industrial partner, the Committee recommends that performance parameters of the pilot plant be jointly reviewed and validated by the industry partner to ensure alignment with commercial-scale deployment requirements.
• The proposal presents a promising opportunity for advancing domestic capabilities in rare-earth processing</td></tr>
<tr><td>Recommendation</td><td colspan="4">Recommended</td></tr>
</table>

Ministry of Mines (Govt. of India)

Pilot Projects for Recovery of Critical Minerals from Overburdens, Tailings, Fly Ash, Red Mud, etc.

TEC (Technical Evaluation Cost Committee) Meeting

Annexure 1

Participation details of TEC members

S No	Name	Designation & Organization	Role	Remarks
i)	Dr Anupam Agnihotri	Director, JNARDDC	Chairperson	Present
ii)	Shri Anshoo Pandey	Director (NCMM), Ministry of Mines	Member	Not Present
iii)	Shri Dinesh Kumar Thawait	DDG (NMH-Mission 2), GSI	Member	Present
iv)	Dr Ramanuj Narayan	Director, CSIR - IMMT	Member	Present
v)	Prof Sanjay Chandra	Professor of Practice, IIT Bombay	Member	Present
vi)	Prof Sagar Pal	Professor, IIT-ISM Dhanbad	Member	Present
vii)	Dr Vilas Tathavadkar	CTO, Hindalco Industries Ltd.	Member	Not Present
viii)	R Anil Kumar	Scientist, JNARDDC	Convenor	Present