Assessing the Sustainability of Solvometallurgy for Black Mass Processing – the LEACH (Low-impact Extraction and Assessment of CHemical solvometallurgy) Tool

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Guidelines for LEACH application

LEACH Scoring guide

Step 1. Define the assessment scope

1.1. Select module(s):

• Module 1: Solvent formulation

• Module 2: BM leaching

• Module 3: Overall process (combined score)

1.2. Identify all chemical components, additives, and relevant operational conditions.

Step 2. Data collection

2.1 Gather physical/chemical data:

• GHS hazard codes (H-statements)

• Biodegradability and persistence information

• CRM status of reagents

• Market prices of reagents

2.2 Collect process parameters:

• Temperature, reaction time

• Solid-to-liquid ratio

• Selectivity and yield

• PMI and workup steps

• Solvent and reagent recyclability

2.3 Collect regulatory data:

• ADR/RID classification

• Environmental fate (PBT/vPvB status)

Step 3. Assign subcategory penalties

3.1 For each module, apply the ranges and penalties in Table 4.

3.2 For each subcategory (economic, technical, safety):

• Identify which range applies

• Assign the corresponding penalty value

3.3 Document the justification for each penalty (data source + rule applied).

Step 4. Calculate module scores

4.1 Sum all penalty points within the selected module(s).

4.2 For Modules 1 and 2:

• Lower penalty = more sustainable

4.3 For Module 3 (overall process):

• Final Score = 100 − Total Penalties

Step. Interpret results

5.1 Assign qualitative classification:

• ≥75 = ideal / excellent

• 50–75 = acceptable / moderate

• <50 = non-ideal

5.2 Identify high-penalty subcategories as optimisation targets.

5.3 Compare module results to diagnose sustainability bottlenecks.

Step 6. Reporting

6.1 Provide a complete table listing:

• Raw data

• Penalty assignment

• Module totals

6.2 Provide justification notes for reproducibility.

6.3 If evaluating multiple processes, normalise categories to compare profiles.

LEACH application to an organic-acid hydrometallurgy case[1]

Process boundary for scoring.

Aqueous citric acid leachant with 2% v/v H_2O_2 at 80 °C, 60–150 min; solid/liquid 10 g/250 mL; subsequent filtration and oxalate precipitation for downstream recovery. Target critical metal for Module 2/3 selectivity is Co (to keep consistency with our manuscript's framing).

Table 1. Module 1 — Solvent/Formulation

Subcategory	Range chosen	PP	Rationale
Materials cost	10–100 €/kg	7	Lab-scale citric acid/H_2O_2 bracketed as mid-cost; no BOM reported—kept within LEACH's mid tier.
Renewable feedstocks	Partially	5	Citric acid is bio-based/biodegradable; H_2O_2 industrial oxidant → "partially renewable."
CRMs use	None	0	No CRMs in the leachant.
T×t (formulation)	≤ 25 °C, ≤ 1 h	0	Aqueous make-up; no heated blending needed is reported.
Workup (formulation)	Simple/none	0	No solvent purification steps stated.
Stability	No degradation reported	0	No instability of the *formulated* leachant noted.
Biodegradability	Components biodegradable	0	Citric acid readily biodegradable; dilute H_2O_2 decomposes.
PMI (formulation)	< 10	0	Make-up of aqueous solution only.
Recyclability	Not reusable (not reported)	5	No solvent reuse loop described.

Subcategory	Range chosen	PP	Rationale
Safety—Intrinsic	Irritant/oxidizer, non-carcinogen	1	Citric acid irritant; 2% H_2O_2 low-hazard oxidizer; no CMRs reported.
Safety—Handling	PPE cat. 1 (standard lab)	0	Standard goggles/gloves implied.
Safety—Emergency	Basic first-aid only	0	No special fire/explosion scenarios at 2% H_2O_2.
Environmental fate	Biodegradable/inert	0	As above.
Regulatory impact	Not listed	0	No DG transport issues at stated concentrations.

Table 2. BM leaching

Subcategory	Range chosen	PP	Rationale
Yield (Co)	> 90%	0	Co = 90.12% with 2% H_2O_2.
Temperature × time	> 50 °C (≤ 4 h)	4	80 °C for 60–150 min.
Workup	Multiple steps	4	Filtration + downstream oxalate precipitation.
PMI	10–50	2.5	10 g solid in ~250 g solution → order-of-magnitude PMI in this band (leach step only).
Recyclability	Not reusable (not reported)	5	No leach liquor recycle/regeneration shown.
Selectivity (to Co)	< 70%	4	Process co-leaches Ni and Al by design; relative to *Co-selective* goal this incurs penalty.
Safety—Intrinsic	Irritant/oxidizer	1	Aqueous organic acid + dilute H_2O_2; no CMRs.
Safety—Handling	PPE cat. 1–2	4	Acid/oxidizer handling & hot slurry → upgraded PPE.
Safety—Emergency	Basic first-aid	0	No specific fire/spill special measures described at this dilution.
Environmental fate	Biodegradable/inert	0	Citric acid aqueous system.
Regulatory impact	Not listed	0	Not a transport-restricted operation as reported.

Module 3 — Overall process (EcoScale logic within LEACH)

(Integrates economic, technical, and safety dimensions across formulation + leaching.)

- Economic (30%): materials cost 7, renewables 5, CRMs 0 → 12 PP.
- Technical (35%): Yield 0; T×t 4; Workup 4; Stability 0; Biodegradability 0; Recyclability 5; Selectivity 4; PMI 2.5 → 19.5 PP.
- Safety (35%): Intrinsic 1; Handling 4; Emergency 0; Fate 0; Regulatory 0 → 5 PP.

Total PP = 12 + 19.5 + 5 = 36.5 → Module 3 Score = 100 − 36.5 = 63.5.

[1] A. Jumari, C.S. Yudha, M. Nizam, E.R. Dyartanti, S.A. Purwanto, Open Engineering, 2022, 12, 485–494.