Hydrometallurgical research highlights at Aalto University

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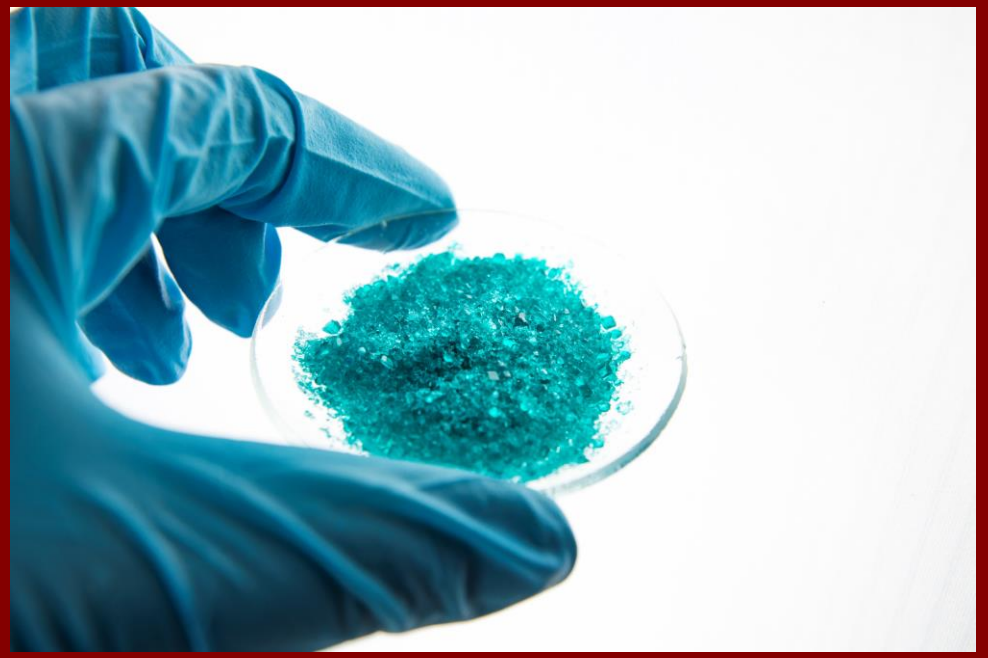
BATCircle Final Seminar 11.3.2021



Hydrometallurgy and Corrosion group

Group consists of ca. 25 researchers conducting research in

- **Hydrometallurgical processing** of primary and secondary raw materials - from fundamental phenomena to process simulation with LCA for environmental impact evaluation
- **Electrochemistry** - electrochemical metal recovery, characterization, as well as corrosion processes
- Utilizing **secondary raw materials** for the development of sustainable processes in **circular economy of metals**

Infrastructure and methods used:

- *Leaching set-ups for different scale of experiments*
- *Set-ups for hydrometallurgical unit processes (precipitation, SX etc)*
- *LIB LAB for safe battery recycling*
- *Electrohemical set ups*
  - *Conventional cells*
  - *Bench pilot EW / ER*
  - *Continuous EQCM*
  - *RDE*
- *Analysis: solution, solids (chemistry, mineralogy)*
- *HSC modelling, simulation based life cycle analysis*
- *Part of RAMI (Raw Materials) Infrastructure*

Example 1 Experimental LIB&NiMH recycling

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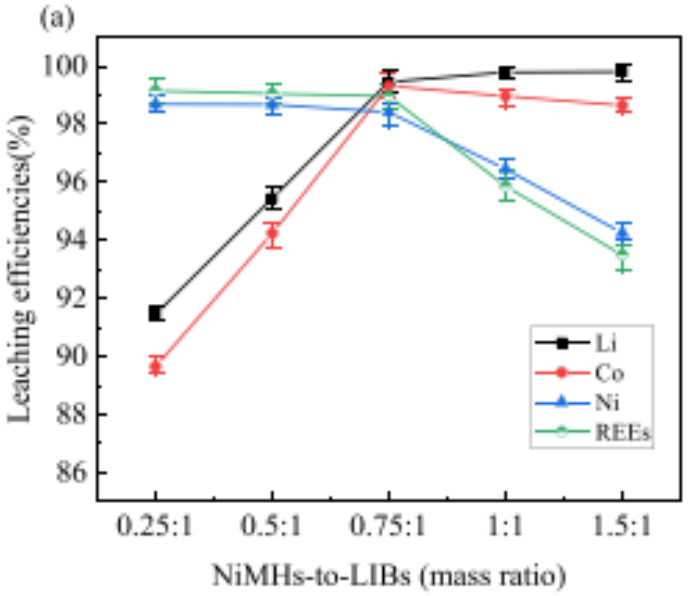
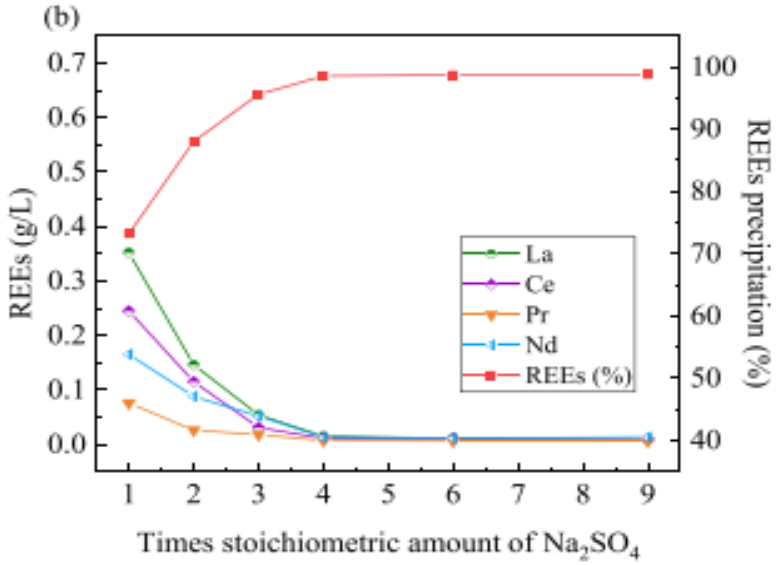
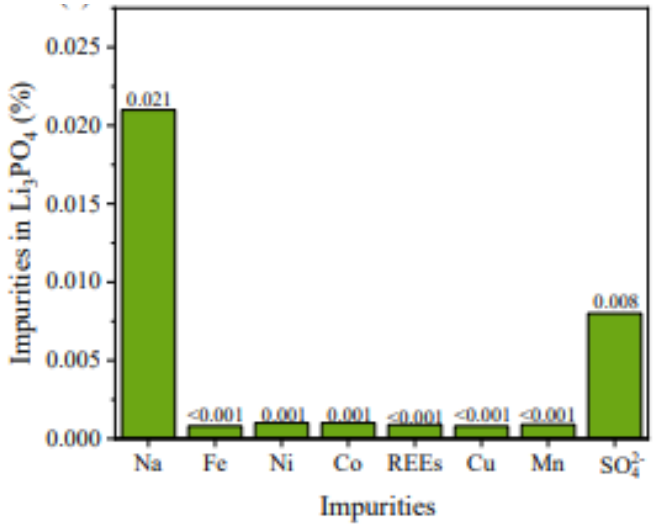
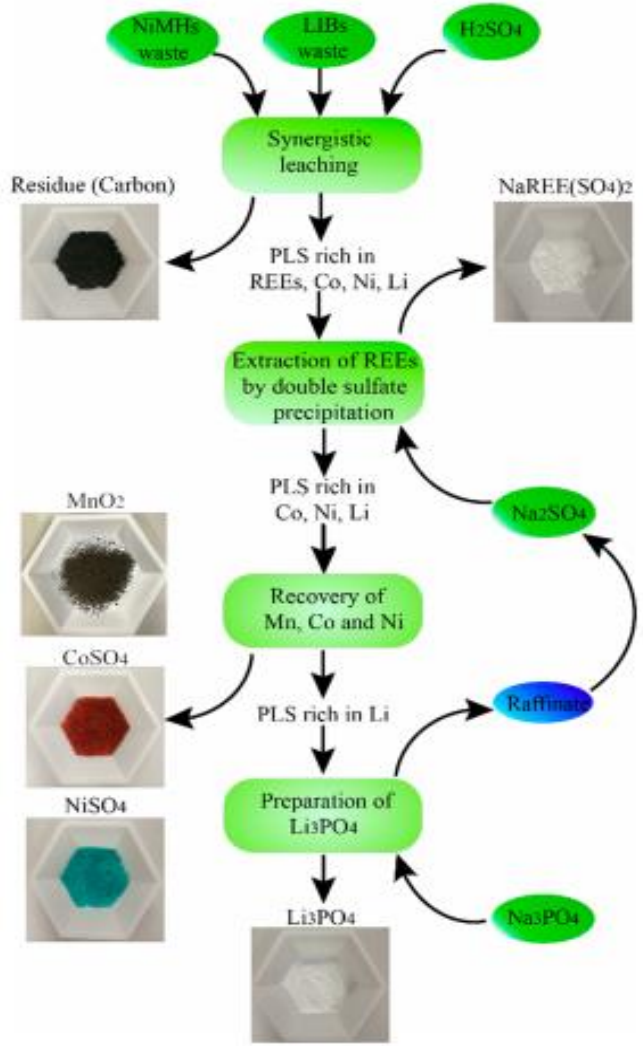
- Experimental study to optimize each unit process
- Suggestion of flowsheet

Synergistic recovery of valuable metals from spent nickel-metal hydride batteries and lithium-ion batteries
Liu, F., Peng, C., Porvali, A., Wang, Z., Wilson, B.P., Lundström M. 2019, ACS Sustainable Chem., 7, 19, 16103-16111.
https://doi.org/10.1021/acssuschemeng.9b02863









Example 2 Process modelling and LCA

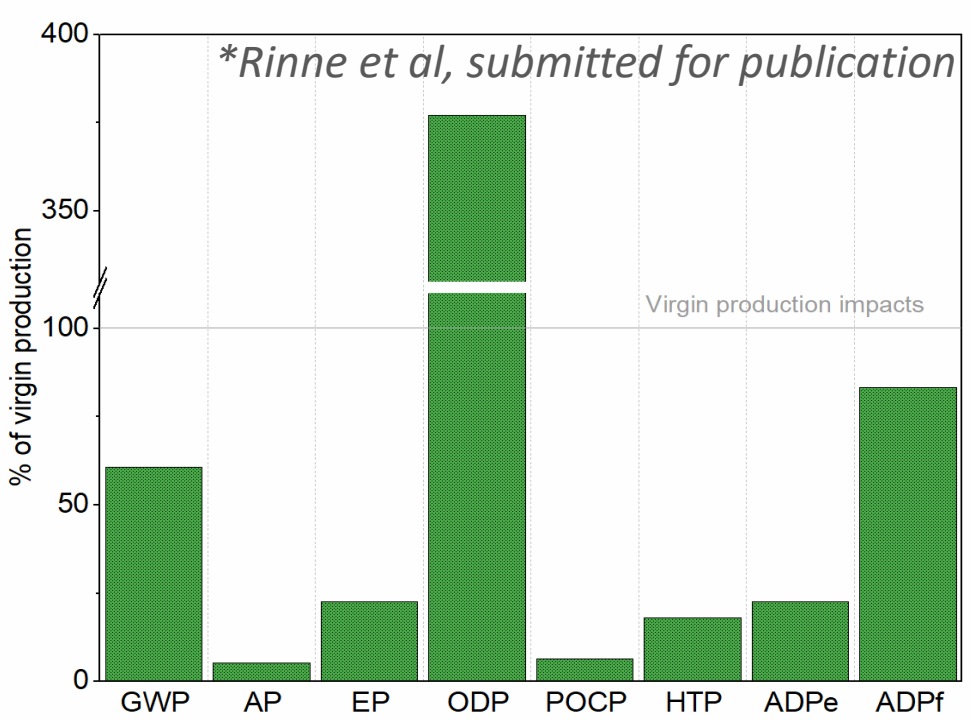
Process modelling allows quantitative determination for e.g. process flows, chemical consumption, product amounts

INPUTS	SCE1	SCE2	SCE3	Unit
Spent NiMHs	0.43	0.43	0.43	kg
Spent LIBs	0.57	0.57	0.57	kg
Process water	26.69	23.84	18.22	kg
Electrical power	0.36	0.30	0.29	kWh
H_2SO_4	3.15	3.36	3.15	kg
Na_2SO_4	0.00	0.00	0.26	kg
$KMnO_4$	0.05	0.05	0.05	kg
NaOH	2.10	2.27	2.10	kg
Na_3PO_4	0.11	0.11	0.11	kg
$Ca(OH)_2$	0.02	0.00	0.00	kg
OUTPUTS	**SCE1**	**SCE2**	**SCE3**	**Unit**
$NiSO_4 \cdot 6H_2O$	1.12	1.12	1.12	kg
$CoSO_4 \cdot 7H_2O$	0.68	0.68	0.68	kg
Li_3PO_4	0.08	0.08	0.08	kg
$NaREE(SO_4)_2$	0.17	0.17	0.17	kg
MnO_2	0.06	0.06	0.06	kg
Solid waste	3.45	0.34	0.54	kg
Waste water	17.31	19.72	19.33	kg
Oxygen	0.02	0.02	0.02	kg
Hydrogen	0.01	0.01	0.01	kg
Water vapor	10.34	3.35	3.08	kg

Table 1. The life cycle inventories of each scenario, normalized for 1 kg of mixed feed.

**Rinne et al, submitted for publication*

Simulation based life cycle analysis allows comparison of recycling processes and their environmental impact to virgin impacts



Recent Battery Publications

from Hydrometallurgy & Corrosion group

Selective lithium recovery and integrated preparation of high-purity lithium hydroxide products from spent lithium-ion batteries

F., Liu, C., Peng, J., Wang, S., Zhou, Z., Chen, B.P. Wilson., M. Lundström. 2021,
Separation and Purification Technology, pp. 118181.
https://doi.org/10.1016/j.seppur.2020.118181

High Purity Nickel Recovery from an Industrial Sidestream Using Concentration and Liquid–Liquid Extraction Techniques

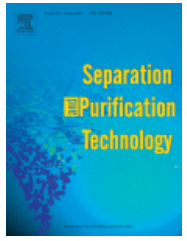
Hu, F., Wilson, B.P., Han, B., Zhang, J., Louhi-Kultanen, M., M. Lundström. JOM, **72,** 831–838 (2020). https://doi.org/10.1007/s11837-019-03928-4

Low-acid leaching of lithium-ion battery active materials in Fe-catalyzed Cu-H2SO4 system

Porvali, A., Shukla S., Lundström M.
2020 in Hydrometallurgy, 195 (2020) 105408
https://doi.org/10.1016/j.hydromet.2020.105408

Nickel Metal Hydride Battery Waste: Mechano-hydrometallurgical Experimental Study on Recycling Aspects

Porvali, A. Ojanen, S., Wilson, B.P., Serna-Guerrero, R., Lundström, M. 2020 in *Journal of Sustainable Metallurgy*
https://doi.org/10.1007/s40831-019-00258-2



Lithium ion battery active material dissolution kinetics in Fe(II)/Fe(III) catalyzed Cu-H2SO4 leaching system

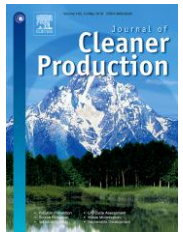
Porvali, A., Chernyaev, A., Shukla, S., & Lundström, M. 2019 in Separation and Purification Technology **https://doi.org/10.1016/j.seppur.2019.116305**

Mechanical and hydrometallurgical processes in HCl media for the recycling of valuable metals from Li-ion battery waste

Porvali, A., Aaltonen, M., Ojanen, S., Velazquez-Martinez, O., Eronen, E., Liu, F., Wilson, B. P., Serna, R., Lundström, M.
2019 in Resources, Conservation & Recycling
https://doi.org/10.1016/j.resconrec.2018.11.023

Challenging the concept of electrochemical discharge using salt solutions for lithium-ion batteries recycling

Ojanen, S., Lundström, M., Santasalo-Aarnio, A., Serna Guerrero, R.,
2018 in WASTE MANAGEMENT https://doi.org/10.1016/j.wasman.2018.03.045



Distributions of lithium-ion and nickel-metal hydride battery elements in copper converting

Tirronen, T., Sukhomlinov, D., O'Brien, H., Taskinen, P. & Lundström, M.
2017 in Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2017.09.051

Lanthanide-alkali double sulfate precipitation from strong sulfuric acid NiMH battery waste leachate

Porvali, A., Wilson, B. P., Lundström, M.
2018 in WASTE MANAGEMENT https://doi.org/10.1016/j.wasman.2017.10.031

Selective reductive leaching of cobalt and lithium from industrially crushed waste Li-ion batteries in sulfuric acid system.

Peng C., Hamuyuni J., Wilson B.P., Lundström M.
2018 in WASTE MANAGEMENT https://doi.org/10.1016/j.wasman.2018.02.052

recycling

Leaching of Metals from Spent Lithium-Ion Batteries

Aaltonen, M., Peng, C., Wilson, B.P., & Lundström, M.
2017 in *Recycling* *https://doi.org/10.3390/recycling2040020*

Recent Battery Publications

from Hydrometallurgy & Corrosion group

Synergistic recovery of valuable metals from spent nickel-metal hydride batteries and lithium-ion batteries
Liu, F., Peng, C., Porvali, A., Wang, Z., Wilson, B.P., Lundström M. 2019, ACS Sustainable Chem., 7, 19, 16103-16111. https://doi.org/10.1021/acssuschemeng.9b02863

Extraction of Li and Co from industrially produced Li-ion battery waste – Using the reductive power of waste itself
Peng, C., Liu, F., Aji, A.T., Wilson, B.P., Lundström M.
95 (2019) 604-611 https://doi.org/10.1016/j.wasman.2019.06.048

Recovery of High-Purity MnO2 from the Acid Leaching Solution of Spent Li-Ion Batteries
Peng, C., Chang, C., Wang, Z., Wilson, B.P. & Lundström, M. 2019," JOM, pp. 1-10. https://doi.org/10.1007/s11837-019-03785-1

Biomass-Assisted Reductive Leaching in H_2SO_4 Medium for the Recovery of Valuable Metals from Spent Mixed-Type Lithium-Ion Batteries
Chen, Y., Chang, D., Liu, N., Hu, F., Peng, C., Zhou, X., He, J., Jie, Y., Wang, H. & Wilson, B.P. Lundström, M. ", JOM, pp. 1-8. https://doi.org/10.1007/s11837-019-03775-3

Integration of battery leach solution into primary Ni production using solvent extraction
Agarwal, V., Khalid, M.K., Porvali, A., Wilson, B.P. & Lundström, M. 2019, "Recycling of spent NiMH batteries: ", Sustainable Materials and Technologies, pp.

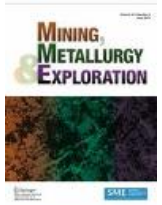
e00121. https://doi.org/10.1016/j.susmat.2019.e00121

Recycling of spent NiMH batteries: Integration of battery leach solution into primary Ni production using solvent extraction
Agarwal, V., Khalid, M.K., Porvali, A., Wilson B.P., Lundström M.
2019 in Waste Management, 95 (2019) 604-611
https://doi.org/10.1016/j.susmat.2019.e00121

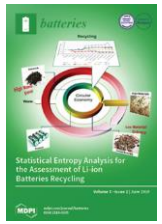
Sulfation Roasting Mechanism for Spent Lithium-Ion Battery Metal Oxides Under SO_2-O_2-Ar Atmosphere
Shi, J., Peng, C., Chen, M., Li, Y., Eriç, H., Klemettinen, L., Lundström, M., Taskinen, P. & Jokilaakso, A. 2019. JOM. https://doi.org/10.1007/s11837-019-03800-5

Selective extraction of lithium (Li) and preparation of battery grade lithium carbonate (Li_2CO_3) from spent Li-ion batteries in nitrate system
Peng C., Liu, F., Wang, F., J., Wilson B.P., Lundström M.
2019 in Journal of Power Sources, 415 (2019) 179-188
https://doi.org/10.1016/j.jpowsour.2019.01.072

Lithium Recovery by Precipitation from Impure Solutions – Lithium Ion Battery Waste
Han, B., Porvali, A., Lundström, M., Louhi-Kultanen, M.
2018 in *Chemical Engineering & Technology* https://doi.org/10.1002/ceat.201700667



Circulation of Sodium Sulfate Solution Produced During NiMH Battery Waste Processing
Porvali, A., Agarwal, V., Lundström, M.,
2019 in *Mining, Metallurgy & Exploration* https://doi.org/10.1007/s42461-019-0086-2



On the Use of Statistical Entropy Analysis as Assessment Parameter for the Comparison of Lithium-Ion Battery Recycling Processes
Velazquez-Martinez, O., Porvali, A., van der Boogaart, K.G., Santasalo-Aarnio, A., Lundström, M. Reuter, M., Serna, R.,
2019 in *Batteries (MDPI)* https://doi.org/10.3390/batteries5020041

Recovery of Silver from Dilute Effluents via Electrodeposition and Redox Replacement
Wang, Z., Halli, P., Hannula, P., Liu, F., Wilson, B.P., Yliniemi, K., Lundström, M. 2019 in *Journal of the Electrochemical Society (ECS)* https://iopscience.iop.org/article/10.1149/2.0031910jes/pdf