



**European Training Network for the  
Sustainable, zero-waste valorisation of  
critical-metal-containing industrial process  
residues (SOCRATES)**

**D6.1 First paper by ESR1-15**



This project has received funding from the European Union's EU Framework Programme for Research and Innovation Horizon 2020 under Grant Agreement No 721385 - <http://etn-socrates.eu/>

# Public

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Date:

[20-08-2019]

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## Introduction

The European Training Network for the Sustainable, zero-waste valorisation of critical-metal-containing industrial process residues (SOCRATES) targets ground-breaking metallurgical processes, incl. plasma-, bio-, solvo-, electro- and ionometallurgy, that can be integrated into environmentally friendly, (near-)zero-waste valorisation flow sheets. The SOCRATES consortium brings together all the relevant stakeholders along the value chain, from metal extraction, to metal recovery, and to residual matrix valorisation in added-value applications, such as supplementary cementitious materials, inorganic polymers and catalysts.

The SOCRATES project kicked off in September 2016 and unites a team of young, enthusiastic PhD researchers across the E.U.. Every six months, the full consortium gathers during a Network-Wide Event (NWE) in which the Early Stage Researchers (ESRs) present their results of the past months. Feedback is provided by (co-)supervisors, partners and peers, and the perspectives towards the future are discussed. Furthermore, during these NWEs, the ESRs discuss the academic work (conference posters, presentations, and journal papers).

Below an overview is given of all publications per ESR until August 20, 2019. It should be considered that the different ESRs have a different starting date of their individual PhDs and therefore have progressed to different levels. All final publications are open access and available in online open repositories; they are also listed on the project website under 'Communications' – 'Science communication': [etn-socrates.eu/communications/science-communication/](http://etn-socrates.eu/communications/science-communication/)

## Overview publications

### ESR1 - Thupten Palden – KU Leuven - Biocompatible solvometallurgical leaching methods for low-grade industrial process residues, WP1

**Peer reviewed paper: published**

T. Palden, M. Regadio, B. Onghena, K. Binnemans, Selective Metal Recovery from Jarosite Residue by Leaching with Acid-Equilibrated Ionic Liquids and Precipitation-Stripping, *ACS Sustainable Chemistry and Engineering*, 2019, 4239-4246, DOI:10.1021/acssuschemeng.8b05938

**Peer reviewed paper: submitted**

T. Palden, M. Regadio, B. Onghena, K. Binnemans, Methanesulfonic acid: a green acidic solvent for recovering metals from jarosite residue of the zinc industry, *RSC Green Chemistry*.

**Conference paper**

T. Palden, M. Regadio, K. Binnemans, Selective solvometallurgical leaching of lead and zinc from jarosite residues from the zinc industry, *Proceedings of the 4th International Symposium on Enhanced Landfill Mining (ELFM IV)*, 2018, 133-136

**Conference abstract**

T. Palden, M. Regadio, B. Onghena, K. Binnemans, Selective solvometallurgical leaching of lead and zinc from jarosite using methanesulfonic acid, Presented at International Symposium on Green Chemistry (ISGC 2019), La Rochelle (France), 13-17 May 2019.



## **ESR2 - Ioanna Maria Pateli – Leicester - Ionometallurgical leaching of industrial process residues using deep-eutectic solvents, WP1**

### **Papers in preparation:**

1. I.M. Pateli, A.P. Abbott, K. Binnemans, N.R. Rodriguez, REEs recycling from lamp phosphor residues in deep eutectic solvents, *Green Chemistry*, 2019
2. I.M. Pateli, J. Hartley, S.S.M. Alabdullah, A.P. Abbott, Chemical and electrochemical dissolution of metal oxides in deep eutectic solvents, *tbc (xxxx)*.

### **Conferences abstracts:**

I.M. Pateli, J. Hartley, S.S.M. Alabdullah, A.P. Abbott, Metal oxides processing using deep eutectic solvents, Proceedings of European Metallurgical Conference 2019 (accepted)

## **ESR3 – Samant Nagrai – Metallo - Plasma-driven metal extraction from industrial process residues, WP1**

### **Conference paper published**

Nagraj SK, Chintinne M, Guo M, Blanpain B, Modelling of an Industrial Submerged Plasma Zinc Fuming Process, Proceedings of the 6th International Slag Valorisation Symposium (SVS6), Mechelen 285-288, 2019

### **Conference paper accepted**

Nagraj SK, Chen L, Liu Z, Chintinne M, Guo M, Blanpain B, Determination of Bath/Freeze Lining Interface Temperature Based on the Rheology of Slag, Proceedings of the 11th International Conference on Molten Slags, Fluxes and Salts, Seoul, 2020

### **Conference paper submitted**

Nagraj SK, Chintinne M, Guo M, Blanpain B, Dynamic steady state thermodynamic modelling of submerged plasma slag fuming process, Proceedings of the 9th International Symposium on Lead and Zinc Processing, San Diego, 2020

## **ESR4 - Pelin Altinkaya – Outotec - Hydrometallurgical process for recovery the critical and valuable metal recovery from complex impure process solutions, WP1**

### **Peer reviewed papers: published**

1. Altinkaya, P., Liipo, J., Kolehmainen, E., Haapalainen, M., Leikola, M., Lundström, M., **2019**. Leaching of trace amounts of metals from flotation tailings in cupric chloride solutions, *Mining, Metallurgy & Exploration*, 36, 335-342.
2. Altinkaya, P., Mäkinen, J., Kinnunen, P., Kolehmainen, E., Haapalainen, M., Lundström, M., **2018**. Effect of biological pretreatment on metal extraction from flotation tailings for chloride leaching, *Minerals Engineering*, 129, 47-53. <https://doi.org/10.1016/j.mineng.2018.09.012>
3. Korolev, I., Altinkaya, P., Halli, P., Hannulla, P. M., Yliniemi, K., Lundström M., **2018**. Electrochemical recovery of minor concentrations of gold from cyanide-free cupric chloride leaching solutions, *Journal of Cleaner Production*, 186, 840-850.



**Published Conference Proceedings**

4. Altinkaya, P., Korolev, I., Kolehmainen, E., Haapalainen, M., Lundström, M., 2019. Ferric and Cupric Chloride Leaching of Valuable Metals from Process Residues, Proceedings of the 10th European Metallurgical Conference (EMC), Vol. 2. p. 821-829, Düsseldorf, Germany.

**ESR5 - Stylianos Spathariotis - Leicester - Electrowinning of metals in deep-eutectic solvents, WP2**

S. Spathariotis, N. Peeters, K. S. Ryder, A. P. Abbott, K. Binnemans and S. Riano, Separation of iron(III), zinc(II) and lead(II) from a choline chloride:ethylene glycol deep eutectic solvent by solvent extraction. In preparation

**ESR6 - Ivan Korolev – Outotec - Selective electrowinning of metals from complex impure solutions, WP2****Peer-review papers published:**

I. Korolev, P. Altinkaya, P. Halli, P.-M. Hannula, K. Yliniemi, M. Lundström. Electrochemical recovery of minor concentrations of gold from cyanide-free cupric chloride leaching solutions, *Journal of Cleaner Production* **186** (2018) 840-850; DOI: [10.1016/j.jclepro.2018.03.177](https://doi.org/10.1016/j.jclepro.2018.03.177)

**Conference papers published:**

K. Yliniemi, Z. Wang, I. Korolev, P.-M. Hannula, P. Halli, M. Lundström. Effect of Impurities in Precious Metal Recovery by Electrodeposition-Redox Replacement Method from Industrial Side-Streams and Process Streams, *ECS Transactions* **85** (2018) 59-67; DOI: [10.1149/08504.0059ecst](https://doi.org/10.1149/08504.0059ecst).

I. Korolev, E. Kolehmainen, M. Haapalainen, K. Yliniemi, M. Lundström. Gold Recovery from Chloride Leaching Solutions by Electrodeposition-Redox Replacement Method, *European Metallurgical Conference (EMC 2019)*, June 23-26, 2019, Düsseldorf, Germany.

**Other**

I. Korolev, K. Yliniemi, M. Haapalainen, M. Lundström. From metal-containing industrial waste towards circular economy of metals: European Training Network SOCRATES, *Transactions of the IMF* **96** (2018) 59-61; DOI: [10.1080/00202967.2018.1419922](https://doi.org/10.1080/00202967.2018.1419922)

**ESR7 - KU Leuven – Ultrasound- and microwave-assisted non-aqueous solvent extraction in milliflow reactors, WP2**

No publications. The contract of the recruited ESR was stopped before any publication was finalised. No new ESR has been recruited.

**ESR8 - Giacomo Damilano – KU Leuven - Synthesis of extractants and ionic liquids from renewable chemicals, WP2****Peer-review papers published:**

G. Damilano, K. Binnemans and W. Dehaen, *Org. Biomol. Chem.*, 2019.

**Peer-review papers submitted:**

None



**Peer-review papers to be submitted:**

Advancements in the one-pot synthesis of symmetrical 1,3-dialkylimidazolium salts: solvents, surfactants, extractants, and physical gelators<sup>‡</sup> – Under writing

Analysis on the effects of thiol substitution in low transition temperature mixtures (LTTMs)<sup>‡</sup> – Under writing

Comparison of 1-butyl-3-methyl-imidazolium tetrafluoroborate ionic liquids with different configurational isomers of the cation – Under writing

**ESR9 - Roberto Macchieraldo – Bonn - Study of solvent miscibility by computational methods, WP2****Peer-review papers published:**

1. Macchieraldo, [...], Kirchner. "Hydrophilic ionic liquid mixtures of weakly and strongly coordinating anions with and without water"
2. Gehrke, [...], Kirchner. "Understanding the fluidity of condensed phase systems in terms of voids--- Novel algorithm, implementation and application"
3. Macchieraldo, [...], Binnemans, Kirchner. "Tuning Solvent Miscibility: A Fundamental Assessment at the Example of Induced Methanol/n-Dodecane Phase Separation"
4. Hollóczki, Oldamur, et al. "Interfacial Domain Formation Enhances Electrochemical Synthesis."

**ESR10 – Gwydyon Marchelli – UBonn - In-silico design of selective metal extractants, WP2****Peer-review papers published:**

M. von Domaros, E. Perlt, J. Ingenmey, **G. Marchelli**, B. Kirchner, *Peacemaker 2: Making clusters talk about binary mixtures and neat liquids*, *SoftwareX* (2018), **7**, 356-359. DOI: 10.1016/j.softx.2018.11.002

J. Ingenmey, J. Blasius, **G. Marchelli**, A. Riegel, B. Kirchner, *A Cluster Approach for Activity Coefficients: General Theory and Implementation*, *J. Chem. Eng. Data* (2019), **64**, 255-261. DOI: 10.1021/acs.jced.8b00779

**Poster in preparation**

G. Marchelli, J. Ingenmey, J. Blasius, B. Kirchner, *Activity coefficients of binary mixtures via Quantum Cluster approach*, 55th Symposium on Theoretical Chemistry 22.09.2019 - 26.09.2019, Rostock

**ESR11 – Jennifer Astoveza – Kerneos - Residual matrix valorisation as supplementary cementitious materials with calcium aluminate binders, WP3****Journal Publication**

*J. Astoveza; R. Trauchessec; R. Soth ; Y. Pontikes, Fe-rich Slag Reactivity in Calcium Aluminate Blended Cement – first draft expected at the end of November 2019*



## Conference Participations

1. J. Astoveza; R. Trauchessec ; R. Soth ; J. Salminen ; Y. Pontikes, *Assessing the reactivity of industrial by-products in calcium aluminate cement-based formulations, Proceedings of the 6<sup>th</sup> International Slag Valorisation Symposium (SVS), Mechelen (Belgium), 1-5 April 2019 – poster*
2. J. Astoveza; R. Trauchessec ; R. Soth ; Y. Pontikes, *Calcium Aluminate Blended Cements Incorporating Engineered Residues, Séminaire de l'Ecole Doctorale C2MP, Metz (France), 6 June 2019 – poster*
3. J. Astoveza; A. Abadias ; R. Soth ; R. Trauchessec ; M. Reuter ; Y. Pontikes, *Industrial By-Products as Non-Conventional Supplementary Cementitious Material, Proceedings of the Forum of Young Researchers in Sustainable Building 2019 (YRSB19), Prague (Czech Republic), 2-4 July 2019 – oral presentation*
4. J. Astoveza; R. Trauchessec; R. Soth, *Quantifying the Degree of Fe-rich Slag Hydration in Calcium Aluminate Blended Cement by Image Analysis of SEM-BSE and XCT data ,International Process Metallurgy Symposium (IPMS 2019), Espoo, Finland, 5-6 November 2019 – oral presentation*
5. J. Astoveza; R. Trauchessec; R. Soth ; Y. Pontikes, *The Effect of Sulfate Content to the Properties of Calcium Aluminate Blended Cement Incorporating Fe-rich Slag, Concrete Solutions Towards Carbon Neutral Constructions by 2050 (GRS 2020), Ventura, CA, US, 22-23 February 2020 – not yet known, on-going drafting of abstract*

## ESR12 - Christina Siakati – KU Leuven - Iron-rich inorganic polymers derived from residual matrices, WP3

- **Published:**

1. C. Siakati, A. Peys, Y. Pontikes, *Inorganic polymers from FeO<sub>x</sub>-CaO-SiO<sub>2</sub> slags: Influence of CaO/FeO ratio on reactivity and strength development*, Materials Science & Technology 2018, Columbus, (Ohio, USA), 06 November 2018, abstract
2. Siakati C, Douvalis AP, Peys A, Ziogas P, Pontikes Y. Impact of the solidification path of FeO<sub>x</sub>-SiO<sub>2</sub> slags on the resultant inorganic polymers. Journal of the American Ceramic Society. 2019. Oct 24, DOI:10.1111/jace.16869
3. Peys A, Douvalis AP, Siakati C, Rahier H, Blanpain B, Pontikes Y. The influence of air and temperature on the reaction mechanism and molecular structure of Fe-silicate inorganic polymers. Journal of Non-Crystalline Solids. 2019 Dec 15;526:119675.
4. C. Siakati, A. P. Douvalis, A. Peys, Y. Pontikes, *Binary, ternary and quaternary Fe-rich slags: Influence of Fe and Si substitution by Ca and Al on the atomic structure and reactivity*, Proceedings of the 6<sup>th</sup> International Slag Valorisation Symposium, Mechelen (Belgium), 01-05 April 2019, conference paper

- **Submitted:**

1. Siakati C, Macchieraldo R, Kirchner B, Tielens F, Peys A, Seveno D, Pontikes Y. Unravelling the nano-structure of a glassy CaO-FeO-SiO<sub>2</sub> slag by molecular dynamics simulation. Journal of Non-Crystalline Solids. 2019. (under review)





- **Under preparation**

1. Siakati C, Macchieraldo R, Kirchner B, Tielens F, Peys A, Seveno D, Pontikes Y. Elucidating the impact of chemical variability on the nano-structure and reactivity of Fe-rich slags. (To be submitted)
2. Siakati C, Douvalis AP, Peys A, Pontikes Y. Fe ions distribution after alkali-activation of Fe-rich slags. (To be submitted)

### **ESR13 – Shuang Yang – UUtrecht - Valorisation of industrial process residues as heterogeneous catalysts, WP3**

No publications yet. The contract of the recruited ESR was stopped before any publication was finalised. A new ESR has been recruited beginning of August 2019.

### **ESR14 - Nikos Nikolopoulos – UUtrecht - Advanced characterisation of metal-containing, low-grade metallurgical residues, WP4**

**Peer-review papers to be submitted:**

N. Nikolopoulos, R.G. Geitenbeek, G.T. Whiting, B.M. Weckhuysen *Waste-derived Zeolites ZSM-5: Effect of impurities*, Applied Catalysis B: Environmental

N. Nikolopoulos, R.G. Geitenbeek, B.M. Weckhuysen *Revealing the influence of impurities on the stability of waste-derived zeolite ZSM-5 under hydrothermal treatment* Green Chemistry

N. Nikolopoulos, A. Malfliet, R.G. Geitenbeek, P. Muchez, B.M. Weckhuysen *Trace In, Sb and Ag in low concentrations incorporated in waste mine tailings* Chemical Geology

**Peer-review papers published:**

Not yet

**Peer-review papers submitted:**

Not yet

**Conference papers published:**

N. Nikolopoulos, R.G. Geitenbeek, G.T. Whiting, B.M. Weckhuysen *Impact of Impurities in Waste Mine Tailings-derived Zeolite ZSM-5 as Catalyst for the Methanol-To-Olefins Reaction*, The Netherlands' Catalysis and Chemistry Conference 2019, Noordwijkerhout (The Netherlands), 4-6 March 2018

### **ESR15 - Alejandro Abadías Llamas – Freiberg - Development of a comprehensive product-centric sustainability indicator framework, WP4**

**Peer-review papers published:**

1. Abadías Llamas, A., Valero Delgado, A., Valero Capilla, A., Torres, C., Hultgren, M., Peltomäki, M., Roine, A., Stelter, M., Reuter, M. A. (2019). Simulation-based exergy, thermo-economic and



environmental footprint analysis of primary copper production. *Minerals Engineering*, 131, 51–65. <https://doi.org/10.1016/j.mineng.2018.11.007>

**Peer-review papers submitted:**

1. Abadías Llamas, A., Bartie, N., Heibeck, M., Stelter, M., Reuter, M. A. (2019). Simulation-based exergy analysis of large circular economy systems: Zinc production coupled to CdTe photovoltaic module life cycle. *Sustainable Metallurgy*. (First review).

**Peer-review papers to be submitted:**

**Conference papers published:**

1. Abadías Llamas, A., Reuter, M. A., Stelter, M., Valero Delgado, A., Hultgren, M., Peltomäki, M., Roine, A. (2018). Thermo-economic Analysis of a Copper Production Plant. From Mine to Cathode. *Sustainable Minerals 18*, Windhoek (Namibia), 14-15 June 2018.

2. Abadías Llamas, A., Hultgren, M., Peltomäki, M., Torres Cuadra, C., Valero Capilla, A., Stelter, M., Valero Delgado, A., Roine, A., Reuter, M. (2018). Resource efficiency evaluation of industrial and circular economy systems using simulation based thermo-economics. Fifth International Conference on Contemporary Problems of Thermal Engineering (CPOTE 2018), Gliwice (Poland), 18-21 September 2018.

3. Astoveza, J., Abadías, A., Soth, R., Trauchessec, R., Reuter, M., Pontikes, Y. (2019). Industrial By-Products as Non-Conventional Supplementary Cementitious Material. Proceedings of the iisBE Forum of Young Researchers in Sustainable Building 2019, Prague (Czech Republic), 1 July 2019, 15-24.

4. Abadías Llamas, A., Valero, A., Bartie, N., Stelter, M., Reuter, M. A. (2019). Process Metallurgy in Circular Economy System Design: The Copper and Base Metal Value Chain. 10<sup>th</sup> Copper International Conference (COPPER 2019), 58<sup>th</sup> annual Conference of Metallurgist (COM 2019), Vancouver (Canada), 18-21 August 2019.

5. Abadías Llamas, A., Bartie, N., Heibeck, M., Stelter, M., Reuter, M. A. (2020). Resource efficiency evaluation of pyrometallurgical solutions to minimize iron-rich residues in the Roast-Leach-Electrowinning process. Proceedings of 9<sup>th</sup> International Symposium on Lead and Zinc Processing (PbZn2020), San Diego (The USA), 23-27 February 2020. (Accepted, to be presented).

