



University of Belgrade, Technical Faculty in Bor



ECOENTER

**30th International Conference Ecological Truth
& Environmental Research
2023**

Proceedings

**Editor
Prof. Dr Snežana Šerbula**





University of Belgrade, Technical Faculty in Bor



ECO-TRUTH

30th International Conference Ecological Truth
& Environmental Research
2023

Proceedings

Editor
Prof. Dr Snežana Šerbula



PROCEEDINGS

30th INTERNATIONAL CONFERENCE

ECOLOGICAL TRUTH AND ENVIRONMENTAL RESEARCH – EcoTER'23

Editor:

Prof. Dr Snežana Šerbula

University of Belgrade, Technical Faculty in Bor

Editor of Student section:

Prof. Dr Maja Nujkić

University of Belgrade, Technical Faculty in Bor

Technical editors:

Jelena Milosavljević, PhD, University of Belgrade, Technical Faculty in Bor

Asst. prof. Dr Ana Radojević, University of Belgrade, Technical Faculty in Bor

Sonja Stanković, MSc, University of Belgrade, Technical Faculty in Bor

Cover design:

Aleksandar Cvetković, BSc, University of Belgrade, Technical Faculty in Bor

Publisher: University of Belgrade, Technical Faculty in Bor

For the publisher: Prof. Dr Dejan Tanikić, Dean

Printed: University of Belgrade, Technical Faculty in Bor, 100 copies, electronic edition

Year of publication: 2023

This work is available under the Creative Commons Attribution-NonCommercial-NoDerivs licence (**CC BY-NC-ND**)

ISBN 978-86-6305-137-9

CIP - Каталогizacija u publikaciji
Narodna biblioteka Srbije, Beograd

502/504(082)(0.034.2)

574(082)(0.034.2)

INTERNATIONAL Conference Ecological Truth & Environmental Research (30 ; 2023)

Proceedings [Elektronski izvor] / 30th International Conference Ecological Truth & Environmental Research - EcoTER'23, 20-23 June 2023, Serbia ; organized by University of Belgrade, Technical faculty in Bor (Serbia) ; co-organizers University of Banja Luka, Faculty of Technology – Banja Luka (B&H) ... [et al.] ; [editor Snežana Šerbula]. - Bor : University of Belgrade, Technical faculty, 2023 (Bor : University of Belgrade, Technical faculty). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemska zahteva: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Preface / Snežana Šerbula. - Tiraž 100. - Bibliografija uz svaki rad.

ISBN 978-86-6305-137-9

а) Животна средина -- Зборници б) Екологија – Зборници

COBISS.SR-ID 118723849



**30th International Conference
Ecological Truth and Environmental Research – EcoTER'23**

is organized by:

**UNIVERSITY OF BELGRADE
TECHNICAL FACULTY IN BOR (SERBIA)**

Co-organizers of the Conference:

**University of Banja Luka, Faculty of Technology,
Banja Luka (B&H)**

**University of Montenegro, Faculty of Metallurgy and Technology,
Podgorica (Montenegro)**

University of Zagreb, Faculty of Metallurgy, Sisak (Croatia)

**University of Pristina, Faculty of Technical Sciences,
Kosovska Mitrovica**

Association of Young Researchers Bor (Serbia)



30th International Conference Ecological Truth & Environmental Research
20–23 June 2023, Serbia

Gold Donor of the Conference



ElixirFondacija

HONORARY COMMITTEE

Dr. Petar Paunović

(Zaječar, Serbia)

Prof. Dr Zvonimir Stanković

(Bor, Serbia)

Prof. Dr Velizar Stanković

(Bor, Serbia)

Prof. Dr Milan Antonijević

(Bor, Serbia)

Dragan Randelović, Association of Young Researchers Bor

(Bor, Serbia)

Toplica Marjanović, Association of Young Researchers Bor

(Bor, Serbia)

Mihajlo Stanković, Special Nature Reserve Zasavica

(Sremska Mitrovica, Serbia)

SCIENTIFIC COMMITTEE**Prof. Dr Snežana Šerbula, *President***

Prof. Dr Alok Mittal (India)	Prof. Dr Yeomin Yoon (United States of America)
Prof. Dr Jan Bogaert (Belgium)	Prof. Dr Chang-min Park (South Korea)
Prof. Dr Aleksandra Nadgórska-Socha (Poland)	Prof. Dr Faramarz Doulati Ardejani (Iran)
Prof. Dr Luis A. Cisternas (Chile)	Prof. Dr Ladislav Lazić (Croatia)
Prof. Dr Wenhong Fan (China)	Prof. Dr Natalija Dolić (Croatia)
Prof. Dr Martin Brtnický (Czech Republic)	Prof. Dr Milutin Milosavljević (Kosovska Mitrovica)
Prof. Dr Isabel M. De Oliveira Abrantes (Portugal)	Prof. Dr Nenad Stavretović (Serbia)
Prof. Dr Shengguo Xue (China)	Prof. Dr Ivan Mihajlović (Serbia)
Prof. Dr Tomáš Lošák (Czech Republic)	Prof. Dr Milovan Vuković (Serbia)
Prof. Dr Maurice Millet (France)	Prof. Dr Nada Blagojević (Montenegro)
Prof. Dr Murray T. Brown (New Zealand)	Prof. Dr Darko Vuksanović (Montenegro)
Prof. Dr Xiaosan Luo (China)	Prof. Dr Irena Nikolić (Montenegro)
Prof. Dr Daniel J. Bain (United States of America)	Prof. Dr Šefket Goletić (B&H)
Prof. Dr Che Fauziah Binti Ishak (Malaysia)	Prof. Dr Džafer Dautbegović (B&H)
Prof. Dr Richard Thornton Baker (United Kingdom)	Prof. Dr Borislav Malinović (B&H)
Prof. Dr Mohamed Damak (Tunisia)	Prof. Dr Slavica Sladojević (B&H)
Prof. Dr Jyoti Mittal (India)	Prof. Dr Nada Šumatić (B&H)
Prof. Dr Miriam Balaban (United States of America)	Prof. Dr Snežana Milić (Serbia)

Prof. Dr Fernando Carrillo-Navarrete
(Spain)

Prof. Dr Pablo L. Higuera
(Spain)

Prof. Dr Mustafa Cetin
(Turkey)

Prof. Dr Mauro Masiol
(Italy)

Prof. Dr George Z. Kyzas
(Greece)

Prof. Dr Mustafa Imamoğlu
(Turkey)

Prof. Dr Petr Solzhenkin
(Russia)

Prof. Dr Dejan Tanikić
(Serbia)

Prof. Dr Milan Trumić
(Serbia)

Dr Jasmina Stevanović
(Serbia)

Dr Dragana Randelović
(Serbia)

Dr Viša Tasić
(Serbia)

Dr Ljiljana Avramović
(Serbia)

Dr Stefan Đorđievski
(Serbia)

ORGANIZING COMMITTEE

Prof. Dr Snežana Šerbula, *President*

Prof. Dr Snežana Milić, *Vice President*

Prof. Dr Đorđe Nikolić, *Vice President*

Prof. Dr Marija Petrović Mihajlović

Prof. Dr Milan Radovanović

Prof. Dr Milica Veličković

Prof. Dr Danijela Voza

Prof. Dr Maja Nujkić

Prof. Dr Žaklina Tasić

Dr Ana Simonović

Dr Tanja Kalinović

Dr Ana Radojević

Dr Jelena Kalinović

Dr Jelena Milosavljević

Sonja Stanković, MSc

Miljan Marković, MSc

Vladan Nedelkovski, MSc

Aleksandar Cvetković, BSc

PREFACE

The 30th international conference Ecological Truth & Environmental Research – EcoTER'23 kept three areas in focus: ecology, environmental protection and sustainable development. The conference will be held on Mt Stara Planina in hotel Stara Planina, Serbia, 20–23 June 2023. The monograph is published on the occasion of the 30th anniversary of the conference. On behalf of the scientific and organizing committee, it is a great honor and pleasure to wish all the participants a warm welcome to the conference.

The monograph is published on the occasion of the 30th anniversary of the conference.

We hope to convey the message of the conference, which is that a transformation of attitudes and behavior would bring the necessary changes. This is also an opportunity for the participants who are experts in this field to exchange their experiences, expertise and ideas, and also to consider the possibilities for their collaborative research.

The 30th international conference Ecological Truth & Environmental Research – EcoTER'23 is organized by the University of Belgrade, Technical Faculty in Bor, and co-organized by the University of Banja Luka, Faculty of Technology, the University of Montenegro, Faculty of Metallurgy and Technology – Podgorica, the University of Zagreb, Faculty of Metallurgy – Sisak, the University of Pristina, Faculty of Technical Sciences – Kosovska Mitrovica and the Association of Young Researchers, Bor.

These Proceedings 103 papers from the authors coming from the universities, research institutes and industries in 11 countries: Australia, USA, Brazil, Spain, Portugal, Libya, Italy, Bulgaria, Bosnia and Herzegovina, North Macedonia, and Serbia.

As a part of this year's conference, the 5th Student Session – EcoTERS'23 is being held. We appreciate the contribution of the students and their mentors who have also participated in the conference.

The support of the Gold donor and their willingness and ability to cooperate has been of great importance for the success of the EcoTER'23. The organizing committee would like to extend their appreciation and gratitude to the Gold donor of the conference for their donation and support.

We appreciate the effort of all the authors who have contributed to these Proceedings. We would also like to express our gratitude to the members of the scientific and organizing committees, reviewers, speakers, chairpersons and all the conference participants for their support to the EcoTER'23. Sincere thanks go to all the people who have contributed to the successful organization of the EcoTER'23.

Prof. Snežana Šerbula,

President of the scientific and organizing committee

TABLE OF CONTENTS

Plenary Lecture

- Lidija Mančić, M. E. Rabanal, B. Marinković*
OPTICALLY ACTIVE NANOMATERIALS FOR ENVIRONMENTAL
REMEDICATION 2

Invited Lectures

- Aleksandra A. Jovanović*
THE EXTRACTION OF ACTIVE COMPOUNDS FROM PLANT WASTE:
THE POTENTIAL IN HUMAN AND INDUSTRIAL APPLICATIONS AS
THE CONCEPT OF ZERO WASTE IN THE CIRCULAR ECONOMY 7
- Tanja Brdarić*
ELECTROCHEMICAL ADVANCED OXIDATION PROCESSES FOR
WASTEWATER TREATMENT: RECENT ADVANCES AND
PERSPECTIVES 18
- Mirjana Marković, S. Radmanović, Đ. Čokeša, N. Potkonjak*
HUMIC ACIDS IN THE ENVIRONMENT 30
- Mira Stanković, M. Prokopijević, D. Bartolić, J. Stevanović, F. Andrić, K. Radotić*
ADVANCED OPTICAL TOOLS APPLIED ON HONEY SAMPLES FOR
BEE HEALTH STATUS MONITORING 40
- Dragana Bartolić, M. Nikolić, M. Stanković, M. Prokopijević, M. Algara,
S. Stanković, K. Radotić*
ESTIMATION OF THE ANTIFUNGAL ACTIVITY OF THE TWO
DIFFERENT CARBON DOTS AGAINST *Aspergillus flavus* 47

Conference Papers

Environmental monitoring and impact assessment

- Ana Čučulović, J. Stanojković, R. Čučulović, M. Stanković*
RADIOACTIVITY IN SOIL AND MOSSES FROM THE SPECIAL
NATURE RESERVE OF ZASAVICA IN 2021 56
- Djurdja Petrov, M. Ocokoljić, N. Galečić, D. Skočajić, I. Simović*
Chaenomeles × *superba* 'PINK LADY' IN DESIGNING PRIVATE
GARDENS IN CONDITIONS OF CLIMATE CHANGE 62

Mirjana Đurašević, I. Čeliković, I. Kandić, T. Milanović, A. Samolov, N. Mladenović Nikolić, A. Kandić	
ACTIVITY CONCENTRATIONS OF ^{210}Pb , ^{137}Cs , AND ^{40}K IN WILD MUSHROOMS FROM SERBIA AND THEIR EFFECTIVE DOSE TO INGESTION	69
Jelena Čović, M. Z. Momčilović, M. Randelović	
LANTHANUM IMMOBILIZED ONTO GRAPHENE AS A CATALYST DESIGNED FOR ELECTROCHEMICAL APPLICATIONS	75
Jelena Čović, M. Z. Momčilović, M. Randelović	
NITROGEN DOPED CARBON MICROSPHERES SUPPORTED ONTO MWCNT AS NOVEL ELECTRODE MATERIAL	82
Aleksandra Nesic, S. Meseldzija, M. Momcilovic	
SUSTAINABLE PECTIN MONOLITH CRYOGELS	88
Daniela Djikanović, O. Prodanović, J. Dragišić Maksimović, J. Jovanović, A. Kalauzi, D. Spasojević, K. Radotić	
INVESTIGATION OF SILICA-LIGNIN INTERACTION. APPLICATION OF AFM AND FLUORESCENCE TECHNIQUES	94
Vesna Djikanović, J. Čanak Atlagić, K. Zorić, S. Andjus, M. Ilić, V. Nikolić, K. Jovičić	
COMPOSITION OF THE FISH COMMUNITY OF THE RIBNICA RIVER WITH RESPECT TO THE CONSERVATION STATUS	99
Nikola Marinković, B. Tubić, A. Atanacković, N. Popović, J. Tomović, M. Raković, M. Paunović	
INDICATIVE ECOLOGICAL STATUS ASSESSMENT OF RIBNICA RIVER (KOLUBARA BASIN) BASED ON AQUATIC MACROINVERTEBRATES	104
Tamara Petronijević, I. Kostić Kokić, T. Anđelković, B. Zlatković, K. Kitanović, D. Bogdanović, N. Stanković	
INFLUENCE OF FREEZING ON NITRATE AND NITRITE CONTENT IN RADISH, PARSLEY LEAF AND CELERY ROOT	109
Marija Matić, D. Pavlović, V. Perović, D. Sekulić, N. Radulović, M. Mitrović, P. Pavlović	
DETERMINATION OF PTEs CONTENT IN LIVESTOCK FODDER AND SOIL IN THE VICINITY OF THERMAL POWER PLANTS AND ASH DISPOSAL SITES	115
Sonja Veljović Jovanović, S. Milić Komić, B. Živanović, A. Sedlarević Zorić, N. Šušić	
LEAF NITROGEN BALANCE INDEX USED TO MONITOR STRESS RESPONSE TO AIR POLLUTION OF DECIDUOUS TREE SPECIES GROWN IN URBAN ZONE OF BELGRADE	122

Bojana Živanović, S. Milić Komić, A. Sedlarević Zorić, A. Jelušić, N. Šušić, S. Marković, S. Veljović Jovanović	
USE OF BIOCHEMICAL METHODS FOR ASSESING OXIDATIVE STRESS IN TREES IN URBAN AREA DURING GROWING SEASON	129
Nikola Šušić, S. Milić Komić, B. Živanović, A. Jelušić, S. Marković, A. Sedlarević Zorić, S. Veljović Jovanović	
ACCLIMATION OF PEDUNCULATE OAK SEEDLINGS TO DIFFERENT LIGHT CONDITIONS IN THE FIRST MONTHS AFTER GERMINATION	135
Božica Vasiljević, J. Đuknić, N. Marinković	
BENTHIC DIATOMS AS PROXY FOR THE ECOLOGICAL CONDITIONS OF THE RIBNICA RIVER, SERBIA	141
Milanka Negovanović, L. Kričak, S. Milanović, J. Marković, N. Simić, S. Ignjatović	
BLASTING MATS FOR THE PROTECTION OF PEOPLE, STRUCTURES AND THE ENVIRONMENT IN PROXIMITY TO THE BLAST SITE	147
Aleksandra Kolarski, V. Srečković, Z. Mijić	
INFLUENCES OF EXTREME SOLAR ACTIVITY ON EARTH ENVIRONMENT – CASE STUDY	154
Maja Poznanović Spahić, A. Gulan, D. Spahić, P. Tančić, S. Sakan, S. Petrović	
AVAILABILITY OF TOXIC ELEMENTS IN ROADSIDE SOILS (HIGHWAY 75, VOJVODINA, SERBIA): IS THERE ANY SIGNIFICANT CONTAMINATION RISK?	160
Tanja Kalinović, A. Radojević, J. Kalinović, J. Milosavljević, S. Šerbula	
MULTICRITERIA EFFICIENCY ASSESSMENT OF THE PINE TREE POTENTIAL FOR THE PHYTOREMEDIATION OF COPPER	167
Žaklina Tasić, M. Petrović Mihajlović, A. Simonović, M. Radovanović, M. Antonijević	
ELECTROCHEMICAL SENSING OF FOLIC ACID	173
Vanja Trifunović, S. Milić, Lj. Avramović, M. Antonijević, M. Radovanović	
POTENTIAL ENVIRONMENT POLLUTANT – INTERMEDIATE PRODUCT OF THE STEEL PRODUCTION PROCESS	179
Natalija Ognjanović, V. Nedelkovski, S. Stanković, S. Milić	
BIOPESTICIDES IN THE ENVIRONMENT	185
Urban and industrial ecology	
Goran Milentijević, M. Agatonović, M. Rančić, M. Milosavljević	
ENVIRONMENTALLY ACCEPTABLE PROCEDURE FOR THE SYNTHESIS OF TETRAETHYLTHIURAMMONOSULFIDE TETS	191

Andela Stojić, D. Tanikić, E. Požega	
TECHNOLOGICAL PROCESSES AS SOURCES OF POLLUTION IN THE ENVIRONMENT	198
Aleksandar Lisica, N. Stojanović, M. Veselinović, J. Petrović, N. Stavretović, M. Tešić	
LONDON PLANE (<i>Platanus × acerifolia</i> (Aiton) Willd.) IN THE STREET TREE LINES OF THE OLD TOWN IN BELGRADE	203
Djordja Petrov, M. Ocokoljić, N. Galečić, D. Skočajić	
APPLICATION OF SPECIES OF THE GENUS <i>Parthenocissus</i> L. IN URBAN GREEN INFRASTRUCTURE – STATE AND PERSPECTIVES	210
Djordja Petrov, M. Ocokoljić, N. Galečić, D. Skočajić, I. Simović	
SECOND FLOWERING OF <i>Philadelphus coronarius</i> L. IN GREEN-BLUE INFRASTRUCTURE OF BELGRADE	216
Dragana Pavlović, M. Matić, V. Perović, O. Kostić, D. Sekulić, M. Mitrović, P. Pavlović	
EFFECTS OF SO ₂ AND NO ₂ ON THE PHOTOSYNTHETIC EFFICIENCY AND CATALASE ANTIOXIDATIVE ENZYME ACTIVITY IN <i>Betula pendula</i> Roth	222
Ermenegilda Vitale, P. Napoletano, C. Arena, A. De Marco	
PLANT-SOIL RELATIONSHIPS IN MEDITERRANEAN SPECIES GROWN ON TECHNOSOLS ENRICHED WITH COMPOST	228
Air, water and soil pollution, prevention and control	
Milica Blažić, M. Milovanović, T. Sekulić, V. Stupar, Z. Živković	
IMPACTS OF PESTICIDE APPLICATION ON THE ENVIRONMENT	235
George Vuković, D. Kovačević, N. Đorđević, M. Perić, S. Knežević, M. Nikolić, B. Vlahović, V. P. Pavlović, G. Rašić, S. Nenadović, M. Ivanović, M. Mirković, V. B. Pavlović	
GREEN SYNTHESIS OF GEOPOLYMER-POLYURETHANE COMPOSITES FOR EM SHIELDING	241
Ana Vukmirović, B. Obrovski, S. Vukmirović, I. Mihajlović	
APPLICATION OF STATISTICAL METHODS FOR THE ANALYSIS OF WASTEWATER TREATMENT PLANT EFFICIENCY	247
Ivana Mihajlović, A. Hgeig, N. Živančev, M. Petrović, M. Novaković	
COMPARISON OF DIFFERENT SORBENTS IN THE HERBICIDE REMOVAL FROM WATER	251
Aleksandar Krstić, I. Bracanović, D. Vasić Anićijević, A. Kalijadis	
VALLME PREPARATION METHOD FOR THE DETERMINATION PHARMACEUTICALS IN WATER	256

Marija Koprivica, J. Petrović, J. Dimitrijević, M. Ercegović, M. Simić, M. Grubišić	
REMOVAL EFFICIENCY OF HEAVY METAL IONS FROM AQUEOUS SOLUTION WITH WASTE TREE BIOMASS HYDROCHARS	261
Nevena Surudžić, D. Spasojević, M. Stanković, M. Spasojević, R. G. A. Elgahwash, R. Prodanović, O. Prodanović	
HORSERADISH PEROXIDASE IMMOBILIZATION WITHIN MICRO-BEADS OF OXIDIZED TYRAMINE-ALGINATE FOR PHENOL REMOVAL FROM WASTEWATER	267
Dragica Spasojević, O. Prodanović, N. Surudžić, D. Djikanović, J. Simonović Radosavljević, K. Radotić, R. Prodanović	
WASTEWATER TREATMENT BY AMINATED PEROXIDASE IN ALGINATE HYDROGEL	272
Branislava Matić, M. Milić	
CONTRIBUTION OF INSTITUTE OF PUBLIC HEALTH OF SERBIA IN MONITORING TRAFFIC-INDUCED AIR POLLUTION IN BELGRADE	276
Nenad Malić, U. Matko, M. Trbić, R. Pijunović, M. Marković	
ALTERNATIVE METHODS OF REHABILITATION (SOIL RECOVERY), RECLAMATION AND REMEDIATION OF MINE TECHNOSOLS	283
Snežana B. Simić, K. A. Markeljić	
PRELIMINARY ECOLOGICAL STATUS ASSESSMENT OF THE GROŠNICA RIVER BASED ON PHYTOBENTHOS	289
Snežana B. Simić, N. B. Đorđević	
AN ASSESSMENT OF THE ECOLOGICAL POTENTIAL OF ŠUMARICE RESERVOIRS (CENTRAL SERBIA) BASED ON PHYTOPLANKTON	295
Miloš Prokopijević, M. Stanković, D. Bartolić, A. Lj. Mitrović, K. Radotić	
FLUORESCENCE CHARACTERISATION OF BISPHEENOL A IN VARIOUS SOLVENTS AND DRINKING WATER	302
Slobodan Ničković, L. Ilić, S. Petković, G. Pejanović, A. Huete, Z. Mijić	
NOVEL APPROACH IN AIRBORNE POLLEN DISPERSION MODELLING	306
Nena Velinov, S. Najdanović, M. Petrović, M. Radović Vučić, M. Kostić, J. Mitrović, A. Bojić	
THE APPLICATION OF SORBENT SYNTHESIZED USING ULTRASOUND FOR REMOVAL OF TEXTILE DYE	312
Milica Petrović, S. Najdanović, N. Velinov, S. Rančev, D. Radivojević, M. Radović Vučić, A. Bojić	
ATMOSPHERIC PRESSURE CORONA PLASMA DEGRADATION OF REACTIVE ORANGE 4 IN DEIONZED AND RIVER WATER	318

Slobodan Najdanović, M. Petrović, N. Velinov, M. Kostić, J. Mitrović, D. Bojić, A. Bojić	
THE INFLUENCE OF TYPE OF SOLVENT ON THE ELECTROCHEMICALLY SYNTHESIZED SORBENTS BASED ON BASIC BISMUTH NITRATES	324
Milena Dimitrijević, S. Kovačević, U. Jovanović, M. Stanić, M. Opačić, I. Santrač, M. Tanović, V. Čurić, I. Spasojević	
APPLICATION OF MICROALGA <i>Chlorella sorokiniana</i> IN WASTEWATER BIOREMEDIATION – CASE OF LAKE ROBULE	330
Milan Gorgievski, M. Marković, N. Štrbac, V. Grekulović, M. Zdravković	
ADSORPTION ISOTHERMS FOR COPPER IONS BIOSORPTION ONTO ONION PEELS	335
Sonja Stanković, V. Nedelkovski, M. Radovanović, S. Milić	
MECHANISM AND KINETICS OF ELECTROCATALYTIC OXIDATION OF PHENOL	341
Jelena Milosavljević, S. Šerbula, A. Radojević, T. Kalinović, J. Kalinović	
ECOENZYMATIC STOICHIOMETRY AS AN EMERGING METHOD IN THE ASSESSMENT OF SOIL HEAVY METAL POLLUTION	348
Protection and preservation of natural resources	
Mihajlo Stanković	
ORCHIDS OF THE ZASAVICA SPECIAL NATURE RESERVE	354
Gordana Šekularac, M. Aksić, T. Dimitrijević (ex. Ratknić), M. Vranešević, N. Gudžić, M. Ratknić	
CLIMATIC BALANCE OF THE WATER FOR THE SOIL OF THE KRUŠEVAC REGION IN CENTRAL SERBIA	361
Gordana Šekularac, M. Aksić, T. Dimitrijević (ex. Ratknić), M. Vranešević, S. Gudžić, N. Gudžić, M. Ratknić	
INFLUENCE OF IRRIGATION METHOD ON THE OCCURRENCE AND INTENSITY OF THE GRAY MOLD OF LETTUCE	367
Aleksandar Stevanović, T. Sekulić, M. Blažić, N. Radić, A. Popović, V. Stupar	
THE IMPACT OF IRRIGATION ON THE QUALITY OF THE ENVIRONMENT AND WATER RESOURCES	373
Aleksandar Stevanović, M. Saulić, M. Blažić, V. Stupar, D. Stojićević, Z. Živković	
BIOPREPARATIONS IN THE FUNCTION OF ORGANIC AGRICULTURE IN FRUIT GROWING AND VITICULTURE	379
Vladanka Stupar, T. Sekulić, M. Blažić, N. Radić, A. Popović, A. Stevanović	
IRRIGATION – IMPACT ON SOIL AS AN ENVIRONMENTAL FACTOR	385

Milan Nedeljković, S. Mladenović, J. Petrović

A RENEWABLE ENERGY SOURCES AND SUSTAINABLE DEVELOPMENT EQUATION

391

Ecological ethics and environmental education

Tatjana Miljojčić

FORGING A SUSTAINABLE FUTURE: THE CIRCULAR ECONOMY IN THE FASHION INDUSTRY

396

Ecotoxicology and environmental safety

Darko Anđelković, M. Branković

CITRATE BUFFERED QuEChERS vs SIMPLIFIED SAMPLE PREPARATION METHOD: COMPARATIVE LC/MS ANALYSIS OF PESTICIDES IN APPLES

402

Darko Anđelković, M. Branković

APPLICABILITY OF THE QuEChERS IN NON-CHROMATOGRAPHY-BASED PESTICIDE ANALYSIS IN APPLES

407

Darko Anđelković, M. Branković

ESI vs APCI IN SELECTED PESTICIDES MS DETECTION IN APPLES

413

Tamara Petronijević, I. Kostić Kokić, Dj. Milošević, M. Stojković Piperac, N. Stanković, T. Anđelković

DIFFERENT GROWTH RESPONSES OF SELECTED REPRESENTATIVES OF PHYTOPLANKTON TO THE PRESENCE OF THE ANTIBIOTIC VANCOMYCIN

420

Tamara Petronijević, I. Kostić Kokić, T. Anđelković, B. Zlatković, D. Stajić, D. Bogdanović, N. Stanković

DETERMINATION OF SEVEN ANIONS IN WATER LETTUCE GROWN IN A NATURAL UNPOLLUTED HABITAT BY ION CHROMATOGRAPHY

426

Milica Zdravković, V. Grekulović, N. Štrbac, J. Suljagić, I. Marković, M. Gorgievski, M. Marković

THE COPPER CORROSION IN CHLORIDE MEDIUM WITH ADDITION OF BLACKBERRY LEAF EXTRACT

432

Hazardous materials and green technologies

Aleksandra A. Jovanović, M. R. Elferjane, M. Gnjatović, B. Bugarski, A. Marinković

PHOSPHOLIPID LIPOSOMES AS A CARRIER FOR ALOE VERA WASTE EXTRACT

438

Aleksandra A. Jovanović, M. R. Elferjane, M. Milošević, M. Gnjatović, A. Marinković	
Vaccinium myrtillus LEAF WASTE EXTRACTS WITH NATURAL DEEP EUTECTIC SOLVENT	444
Danijela Kovačević, N. Đorđević, S. Glišić, B. Vlahović, V. B. Pavlović	
MORPHOLOGICAL INVESTIGATION OF PVDF/MAGNETITE@NC/BaTiO ₃ SEMI-SPHERICAL COMPOSITE MATERIALS FOR OIL REMOVAL	450
Branislava Savić, D. Aćimović, M. Ječmenica Dučić, M. Simić, D. Vasić Anićijević, T. Brdarić	
DEGRADATION OF PHENOL AND SUBSTITUTED PHENOLS: INFLUENCE OF APPLIED POTENTIAL	456
Marija Ječmenica Dučić, D. Aćimović, B. Savić, M. Simić, A. Krstić, D. Vasić Anićijević, T. Brdarić	
DEGRADATION OF DYES MIXTURE BY ELECTROCHEMICAL OXIDATION USING STAINLESS STEEL ELECTRODE	460
Marija Simić, D. Aćimović, B. Savić, M. Ječmenica Dučić, I. Perović, D. Vasić Anićijević, T. Brdarić	
THE OXYGEN EVOLUTION REACTION AT TIN DIOXIDE-CARBON-BASED ELECTRODES	465
Drita Abazi Bajrami, M. Marinkovski, K. Lisichkov, S. Kuvendziev	
OPTIMIZATION OF THE <i>Helichrysum arenarium</i> EXTRACT OBTAINED WITH ULTRASOUND-ASSISTED EXTRACTION	469
Berina Sejdinović	
VIBRATION ISOLATION	475
Uroš Stamenković, I. Marković	
THE INFLUENCE OF AGEING ON THE THERMAL PROPERTIES AND MICROSTRUCTURE OF THE EN AW-6082 GREEN ALUMINIUM ALLOY	482
Ljubiša Balanović, D. Manasijević, I. Marković, U. Stamenković, M. Petrić	
MICROSTRUCTURAL AND THERMAL CHARACTERIZATION OF Bi-Sb-Sn ALLOYS FOR ECOLOGICAL APPLICATION	488
Vladan Nedelkovski, S. Stanković, M. Radovanović, Ž. Tasić, S. Milić	
OPTIMIZATION OF PHENOL ELECTROCHEMICAL OXIDATION USING MODIFIED Ti/SnO ₂ -TYPE ANODES	494
Aleksandar Cvetković, Ž. Tasić, M. Petrović Mihajlović, A. Simonović, M. Radovanović, M. Nujkić, M. Antonijević	
INFLUENCE OF SUBSTITUTES ON THE EFFICIENCY OF ORGANIC CORROSION INHIBITORS	500

Sonja Stanković, M. Nujkić, Ž. Tasić, D. Medić, A. Papludis, S. Milić	
MODIFIED MEMBRANES WITH GRAPHENE OXIDE – REMOVAL OF DYES FROM WASTEWATER	506
Human and ecological risk assessment	
Olga Kostić, D. Pavlović, M. Marković, Z. Miletić, N. Radulović, M. Mitrović, P. Pavlović	
HUMAN HEALTH RISK ASSESSMENT OF PTE _s IN ELECTROFILTER ASH AND CHRONOSEQUENCE FLY ASH FROM “TENT A” DISPOSAL SITES	512
Agriculture: nutrition, organic food and health impacts	
Markola Saulić, V. Trajić, D. Stojićević, A. Stevanović, Z. Živković	
EFFECT OF EXTRACT <i>Ecklonia maxima</i> ON CONDITION OF AGRICULTURAL CROPS	519
Metodi Mladenov	
SUITABILITY OF THE SOILS IN THE MUNICIPALITY OF KOVACHEVTSI, BULGARIA FOR GROWING ON EINKORN WHEAT (<i>Triticum monococcum</i>)	524
Gorica Cvijanović, V. Stepić, M. Bajagić, V. Cvijanović, J. Marinković, N. Đurić	
INFLUENCE OF EFFECTIVE MICROORGANISMS ON THE BASIC PARAMETERS OF SOIL BIOGENICITY IN THE PRODUCTION OF WHEAT AND CORN	529
Vojkan Miljković, R. Ljupković, M. Miljković	
APPLICATION OF CLASSIC THIN LAYER CHROMATOGRAPHY METHOD FOR QUALITATIVE DETERMINATION OF SYNTHETIC FOOD COLORS	535
Alternative energy: efficiency and environmental policy	
Snežana Brković, N. Zdolšek, I. Perović, G. Tasić, M. Seović, S. Mitrović, J. Georgijević	
NOVEL CARBON MATERIAL FOR OER IN VARIOUS ELECTROLYTE SOLUTIONS	540
Nikola Zdolšek, I. Perović, S. Brković, M. Seović, J. Georgijević, S. Mitrović, P. Laušević	
THE EFFECT OF DIFFERENT TYPE OF ELECTROLYTES ON THE DISCHARGE CAPACITY OF Zn-AIR BATTERIES	545
Jelena Georgijević, J. Milikić, N. Zdolšek, I. Perović, S. Brković, S. Mitrović, B. Šljukić	
IRON, COBALT DUAL DOPED CARBON ELECTROCATALYST FOR EFFICIENT WATER SPLITTING	550

Greenhouse effect and global climate change

- Tatjana Dimitrijević, G. Šekularac, M. Ratknić, M. Aksić**
EFFECTS OF CLIMATE CHARACTERISTICS ON THE DIAMETER INCREMENT OF RED OAK IN THE CITY OF BELGRADE (SERBIA) 555
- Milica Blažić, T. Sekulić, V. Stupar, Z. Živković**
GREENHOUSE EFFECT AND GLOBAL CLIMATE CHANGE – IMPACT ON AGRICULTURE 561
- Vojkan Miljković, I. Gajić, Lj. Nikolić**
GLOBAL CLIMATE CHANGES: GREENHOUSE GASSES, CITIES AND PLASTICS 567

Sustainable development and green economy

- Zlata Živković, M. Saulić, D. Stojićević, M. Jevtić, V. Stupar**
ROLE OF NUTRIENTS IN CONTROLLING PLANT DISEASES AND PATHOPHYSIOLOGICAL ALTERATIONS IN PLANTS IN SUSTAINABLE AGRICULTURE. A REVIEW 572
- Zlata Živković, M. Saulić, D. Stojićević, M. Jevtić**
THE WAY OF MANAGING PLANT DISEASES IN SUSTAINABLE AGRICULTURE 578
- Dragan Ugrinov, M. Nikolić**
THE ROLE OF PLANTS IN BIOECONOMY AND CIRCULAR ECONOMY 584
- Vojkan Miljković, I. Gajić, Lj. Nikolić**
AGRICULTURAL WASTE IN SUSTAINABLE AGRICULTURE 589
- Ana Radojević, J. Milosavljević, S. Šerbula, T. Kalinović, J. Kalinović**
RECYCLING OF Li-ION BATTERIES FROM THE END-OF-LIFE VEHICLES: OPPORTUNITY OR LIABILITY IN THE FUTURE? 593

Environmental biology

- Vladimir Topalović, S. Matijašević, V. Savić, J. Nikolić, J. Stojanović, S. Zildžović, S. Grujić**
CRYSTALLIZATION CHARACTERISTICS OF BIOACTIVE POLYPHOSPHATE GLASSES 599

Environmental and material flow management

- Isidora Berežni, T. Marinković, B. Batinić**
ASSESSING THE COMPOSITION OF MUNICIPAL SOLID WASTE IN ŠID 605

Ivan Bracanović, A. Krstić, A. Kalijadis

SYNTHESIS AND CHARACTERISATION OF CARBON NANOMATERIAL USING HYDROTHERMAL CARBONISATION METHOD

612

Hamid Husić, S. Čerčić, V. Aganović

RETROSPECTIVE OF THE PLANNED ACTIVITIES FOR THE REHABILITATION OF THE DAMAGED AREA OF THE FORMER SURFACE MINE ČUBRIĆ

617

Student Section

Students: Ana Smiljković, Isidora Sujić (Serbia)

Mentor: Maja Nujkić (Serbia)

ENVIRONMENTAL AND HEALTH RISK OF CO₂ IN INDOOR ENVIRONMENTS

624

Student: Avram Kovačević (Serbia)

Mentor: Uroš Stamenković (Serbia)

ANTHROPOGENIC MERCURY IN THE ENVIRONMENT: GLOBAL EMISSIONS AND RECYCLING POSSIBILITIES

626

Student: Petar Milanović (Serbia)

Mentors: Uroš Stamenković, Avram Kovačević (Serbia)

THE INFLUENCE OF COOLING RATE ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF C45 CARBON STEEL

628

Student: Milica Denić (Serbia)

Mentor: Jelena Kalinović (Serbia)

AIR POLLUTION WITH CARCINOGENIC SUBSTANCES

630

Student: Gordan Mišić (Serbia)

Mentor: Jelena Kalinović (Serbia)

ACID RAIN AND SMOG – CHEMICAL REACTIONS

632

Student: Milica Denić (Serbia)

Mentor: Ana Radojević (Serbia)

MEDICAL WASTE MANAGEMENT

634

Student: Gordan Mišić (Serbia)

Mentor: Ana Radojević (Serbia)

ENVIRONMENTAL POLLUTION BY PET PACKAGING

636

Student: Marija Stanković (Serbia)

Mentor: Ana Simonović (Serbia)

COPPER CORROSION IN ARTIFICIAL ACID RAIN SOLUTION IN PRESENCE OF 5-PHENYL-1-TETRAZOLE

638

RECYCLING OF LI-ION BATTERIES FROM THE END-OF-LIFE VEHICLES: OPPORTUNITY OR LIABILITY IN THE FUTURE?

Ana Radojević^{1*}, Jelena Milosavljević¹, Snežana Šerbula¹, Tanja Kalinović¹,
Jelena Kalinović¹

¹University of Belgrade, Technical Faculty in Bor, V.J. 12, 19210 Bor, SERBIA

*aradojevic@tfbor.bg.ac.rs

Abstract

The presence of precious metals with much higher content and purity compared to the corresponding ores, the end-of-life lithium-ion batteries (LIBs), used in electric vehicles (EVs), are known as “urban mine” and have become a research hotspot. The growing demand for the EVs will result in generation of significant quantities of waste LIBs, containing both economically and environmentally targeted materials. If not recycled, traction LIBs could be linked to the depletion of scarce metal reserves, such as lithium and cobalt. Low recycling rate, amounting to less than 5%, is currently affecting profitability of the recycling process. Two main recycling routes for LIBs – pyrometallurgy and hydrometallurgy, have numerous advantages and disadvantages. However, research studies have shown that different processes developed on a laboratory scale could result in good recycling outcomes, considering high recovery rates, achieved purity of products, profitability and eco-friendliness of the recycling process.

Keywords: Li-ion batteries, recycling, end-of-life vehicles, electric vehicles.

INTRODUCTION

The lithium (Li) market is predominantly oriented towards the production of all kinds of batteries for portable devices and electric vehicles, with 80% of the global share, followed by the production of ceramic and glass (7%) and lubricating greases (4%). In recent years, Li consumption for battery production considerably increased mostly due to the fast-growing market of electric vehicles (EVs) [1]. The EVs have a great potential to contribute to the significant reduction of the air pollution emissions in the mobility sector if they are powered on the renewable energy. However, traction Li-ion batteries (LIBs) may become problematic from a sustainability point of view, because of high need for scarce metals [2,3]. The most common nonferrous metals used in the production of the LIBs are Ni, Cu, Co, and Li, among which the Co and Li are denoted as a critical raw material since their resources are limited. According to the reports of the US Geological Survey, the majority of Li production comes from a few countries in the world: Australia, Brazil, Argentina, Chile, China, and smaller operations located in Canada, Portugal, the USA, and Zimbabwe [1,4]. More than half of cobalt production in the world originates from Congo, while China controls about 70% of graphite production, which is also needed for the LIB production [5]. Owing to continuing exploration, the total identified Li resources worldwide are around 98 million tons, mostly located in Bolivia ($21 \cdot 10^6$ t), Argentina ($20 \cdot 10^6$ t), the USA ($12 \cdot 10^6$ t) and Chile ($11 \cdot 10^6$ t). Nevertheless, Blomeke *et al.* [2] showed that the industrial recycling routes are both

economically and environmentally advantageous over the production of the battery components from the raw materials.

At the start of 2019, more than 5.6 million EVs in the world were in use, which is an increase of 64% compared to 2018. By 2040, it is expected that the EVs will account for 58% of all globally sold automobiles [6]. If the LIBs from the end-of-life (EOF) vehicles are hoarded or dumped, non-renewable natural resources are irretrievably wasted. Since the enormous size of the EV's batteries (e.g. the Tesla Model 3 Long Range battery weighs 480 kg) [6], a substantial amount of waste with high economic value will be produced every year, reaching 21 million tons in the period 2015–2040 [5]. The profit of LIB recycling is up to 3300 €/t, with avoided impacts of emitted 5–7 t of CO_{2(eq)} per tonne of EOF LIBs [6]. The current amount of EOL LIBs affects the profitability of the recycling process. However, the number of EOL LIBs is projected to increase by 2030 due to the rising number of the EVs that will reach their EOL [2], since the average usage of the LIBs is 8 to 10 years [5]. According to Wasesa *et al.* [7], the price of waste LIBs must be less than \$227/t in order to be profitable at the lowest incentive condition, while the LIB recycling cost should be \$1803/t at the highest incentive scenario. The variety of active cathode materials and the mixing of unknown elements from the production and utilization are the main reasons for difficult and expensive recovery processes [8]. Nevertheless, the reuse of recovered materials in manufacturing of traction LIBs would cause a reduction for all the considered environmental impacts [9]. According to the European legislation, EOL LIBs need to be recycled with a minimum recovery rate of 65% by 2025, which is the medium level of ambition option of the European Commission proposal. Furthermore, the material-specific recovery rates are also set for the valuable components, such as Co, Ni, and Cu, amounting to 90% as well as for Li amounting to 35% of the recovery rate from the EOL LIBs [10].

The paper aims to analyse the main aspects of available recycling processes for the recoverable materials from the EOL LIBs.

RESULTS AND DISCUSSION

Composition of the LIBs

The main components of the LIB structure are battery shell, cathode, anode, separator, and electrolyte. The battery shell is composed of stainless steel, aluminium or plastic. The cathode consists of conductive carbon, binder polyvinylidene fluoride, Al-foil, and active material. There are five types of cathode active material: lithium nickel manganese cobalt oxide (LiNi_xCo_yMn_zO₂), lithium iron phosphate (LiFePO₄), lithium cobalt oxide (LiCoO₂), lithium manganate (LiMn₂O₄) and lithium nickel cobalt alumina (LiNi_xCo_yAl_zO₂). The anode is usually composed of binder polyvinylidene fluoride, Cu-foil, graphite or conductive carbon, while the electrolyte consists of organic solvents, Li-conductive salts (LiPF₆, LiBF₄ or LiClO₄) and additives [8,11,12].

Available recycling technologies for the EOL LIBs

There are three feasible options for the EOL EVs batteries, depending upon their design, quality, and state of condition: remanufacturing, repurposing, and recycling. Remanufacturing and repurposing extend the usage of the LIBs, while recycling closes the loop [5].

The selection of the recycling process for the EOL LIBs is driven by the difference between the profit of the recycled products and the sum of the costs of the recycling process, other than the recycling rate efficiency and the environmental impact of the process [8]. Dunn *et al.* [13] showed that 15–18% of Co, 9–11% of Li, and 15–17% of Ni demand in 2035, could be met by the closed-loop recycling of the EOL LIBs. As the most valuable component of the LIB, the cathode active materials account for more than 1/3 of the total battery cost [14]. However, if organic solvents and lithium salts are completely recovered from the electrolytes, the profit with a total value of \$3345/t of electrolyte could also be gained [15].

Recycling of cathodes could be done *via* smelting in pyrometallurgy, *via* leaching in hydrometallurgy, or without destruction of the crystalline structure of the electrode active material *via* direct recycling. Combination of the given processes could also be employed, such as co-precipitation route, which is a process between hydrometallurgy and direct recycling. The outcomes of the recycling process can differ considerably regarding the recovered materials, achievable purities of the recycled metals, recovery rates, required infrastructure, process emissions, investments, costs, and revenues [2,14,16].

The metallurgy-oriented methods are widely used on the industrial level, while the direct recycling is still in the research stage, but considered as a promising method during which the cathode active materials from the EOL LIBs are directly regenerated [14]. By November 2022, 44 companies in Canada and the USA, and 47 companies in Europe were already involved in recycling or planning to recycle the LIBs [1]. The pyrometallurgical route is implemented mainly in Europe, Japan and North America, while hydrometallurgical route has been mostly commercialized in China [14]. Latini *et al.* [16] reported the plant capacities of most of the recycling facilities in Europe, North America, and Asia. In Table 1, the data is given for the largest ones, according to the recent capacities.

Table 1 The location, capacities and recycling technology of some LIB recycling facilities [16]

Company (Location)	Capacity (t/year) for specific year	Recycling technology
Umicore (Begum)	7000 (2020)	Pyro/hydrometallurgy
Glencore* (Norway)	7000 (2020)	Pyrometallurgy
Nortvolt AB (Norway)	8000 (2022)	Mechanical/hydrometallurgy
Stena (Sweden)	10000 (2023)	Mechanical/hydrometallurgy
Neometals (Germany)	10000 (2022)	Mechanical/hydrometallurgy
Erasteel Recycling* (France)	20000 (2020)	Pyrometallurgy
INMETCO* (USA)	6000 (2020)	Pyrometallurgy
Glencore (Canada)	7000 (2020)	Pyrometallurgy
Li-Cycle (USA)	60000 (2023)	Hydrometallurgy/co-precipitation
Nippon Recycle Centre Corp.* (Japan)	5000 (2020)	Pyrometallurgy
SungEel Hi Tech (South Korea)	8000 (2020)	Mechanical/hydrometallurgy
Guanghua Sci-Tech (China)	10000 (2020)	Mechanical/hydrometallurgy
Highpower International* (China)	10000 (2020)	Mechanical, pyro/hydrometallurgy
GEM* (China)	30000 (2020)	Mechanical/hydrometallurgy
Huayo Cobalt (China)	65000 (2020)	Mechanical/ hydrometallurgy

* Facility is recycling batteries other than Li-ion batteries, such as Ni-metal hydride battery, NiCd, etc.

The pyrometallurgical route can utilize different LIB chemistries, as well as geometries, without pre-sorting. However, Li could not be recovered unless the formed slag is subsequently refined. The hydrometallurgy-based processes are more chemistry-specific, but necessarily require pre-treatment [16]. More advantages and disadvantages of pyro- and hydrometallurgical-oriented processes are listed in Table 2.

Table 2 The key advantages and disadvantages of the pyro- and hydrometallurgical routes for recycling of end-of-life LIBs [2,8,12,16]

Pyrometallurgy		Hydrometallurgy	
Advantages	Disadvantages	Advantages	Disadvantages
Versatile process	Valuable materials are burnt	High recovery rates	Sorting or pre-treatment needed
High capacity of facilities	Downcycling for Li	Recycling of the electrolytes	Lower capacity of facilities
No sorting or pre-treatment needed	Waste gases treatment needed	High purity of obtained products	Generation of wastewaters
High recovery rates for Co, Ni and Cu	High energy consumption (up to 1700 °C)	Lower energy consumption (up to 100 °C)	High operating costs
Industrial application	Low purity of metals	Low emission of waste gases	Complexity of process
Simple process	Further processing of slag is needed	Recovery of the most LIB components	Wastewater treatment needed

Pyrometallurgy is based on smelting of whole batteries in a furnace at extremely high temperatures in order to recover an alloy of precious metals, such as Ni, Co and Cu. The electrolyte is evaporated in the low-temperature zone of the furnace and proceeded to energy recovery unit, while plastics and graphite parts are burnt in the high-temperature zone. The slag, consisted of Li, Al, Mn, and partly of Fe, is typically forwarded to the low-quality markets, although it could be refined via hydrometallurgy to obtain high-purity metals [12].

Hydrometallurgy is based on the leaching in strong inorganic acids (e.g. H_2SO_4 , HCl, HNO_3) or alkalis (NaOH), with an additional reducing agent (e.g. H_2O_2), for dissolving the cathode active materials, in order to recover them as single-phase metal salts through crystallization, selective precipitation, solvent extraction, or by electrochemical methods. As an environmentally friendly option, the LIBs could be treated by bio-hydrometallurgy (e.g. microbiological metal dissolution or fungal bioleaching), leached with organic acids (e.g. citric, ascorbic, oxalic or malic acid) or with water because Li-salts are soluble in water [12,17,18]. However, some methods are far from the industrial application. Prior to hydrometallurgical route, a pre-treatment is usually applied in order to increase the recovery rate and reduce the high costs [12]: (a) mechanical separation of electrode materials encapsulated in iron and plastic, including crushing, grinding, gravity and magnetic separation; (b) thermal treatment (e.g. vacuum pyrolysis) in which organic additives and binders are pyrolyzed at high temperatures in order to liberate electrode materials from the foils; (c) mechano-chemical treatment, as a grinding technique, is used to decompose the

crystal structure of metal active materials, extracting Co and Li by an acid leaching process at the room temperature; and (d) dissolution treatment used to weaken the adhesive substance by organic solvents. The electrochemical methods (such as electrolytic deposition, electrodialysis, aqueous electrolysis, and molten salt electrolysis), could replace the traditional chemical leaching of the EOL LIBs. In these methods, the recycling efficiency is greatly improved, and at the same time high reagent consumption and environmental hazards are reduced, which are the main disadvantages of the leaching process. However, many of the electrochemical methods are developed only on a laboratory scale [8,17].

The direct recycling consists of separating and regenerating the cathode and anode active materials without decomposing them into elements. The Li-inventory, lost during battery usage, is restored by keeping the particle morphology and crystalline structure, thus recycled product can be directly reused in new LIBs [12]. The direct recycling has the potential to be environmentally and economically sustainable because the energy and water consumption, as well as the emissions of greenhouse gasses and SO_x are much lower compared to the virgin production of the LIB components and pyro/hydrometallurgical recycling routes. Beyond the challenge of repairing the crystal structure of electroactive materials, there are still many obstacles facing the practical application of the direct recovery [19]. Solid-state sintering, hydrothermal regeneration, eutectic molten salts, and thermal, hydrothermal and electrochemical lithiation are some of the methods, mostly developed at the laboratory scale [16,19].

Zhang *et al.* [20] proposed the concept of carbothermal reduction in combination with three-stage leaching as easy and eco-friendly approach to recycle Li from the LIBs with high Al content, with the comprehensive recovery rate of 87.15%. According to Chakraborty and Saha [6], the optimum choice for the LIB recycling is blending of mechanical shredding, electrolyte extraction, electrode dissolution and Co electrochemical reduction. According to the available data, Dunn *et al.* [13] showed that the recycling of LIBs is less expensive in China than in the USA, neither by conducted transport by truck nor train. Blomeke *et al.* [2] emphasized that, in order to manage the high costs associated with transport of spent batteries as hazardous goods, it is crucial to establish a flexible and scalable recycling infrastructure that can meet the needs for the future market growth and utilization. Makwarimba *et al.* [17] concluded that the focus in the future should be on the development of abundant and non-toxic anode, cathode and electrolyte materials for the LIB production, as well on the new battery designs. Despite the progress made in upscaling conventional methods, there are still few medium to large-scale recycling facilities in the world.

CONCLUSION

In future years, it is crucial to establish a sustainable recycling system that will ensure infrastructure readiness and support the needs for much greater volumes of the LIBs – the valuable, but also hazardous kind of waste. The aim of further research must be feasible connection of a complex relationship among recycling companies, manufacturers of the LIBs, and suppliers of the raw materials on a global scale. If the concept of circular economy is applied on LIBs, the loop could be closed, by combining the supply chain management, sustainability assessment, and innovative engineering. Both, the pyro- and hydrometallurgy-

oriented processes have major drawbacks, such as low purity of the recycled products and downcycling of Li, or high complexity and smaller capacity of the processes, respectively. On the other hand, outcomes of various recycling processes on the laboratory scale, have confirmed that recycling of EOL LIBs is a great opportunity, but also a huge liability for the future.

ACKNOWLEDGEMENT

The authors are grateful to the Ministry of Education, Technological Development and Innovation of the Republic of Serbia for financial support, within the funding of the scientific research at the University of Belgrade, Technical Faculty in Bor (No. 451-03-47/2023-01/200131). Our thanks go to English language teacher, Mara Ž. Manzalović from the University of Belgrade, Technical Faculty in Bor, for providing language assistance.

REFERENCES

- [1] Mineral commodity summaries 2023: U.S. Geological Survey, Available on the following link: pubs.er.usgs.gov/publication/mcs2023.
- [2] Blomeke S., Scheller C., Cerdas F., *et al.*, J. Clean. Prod. 377 (2022) 134344.
- [3] Chen Q., Lai X., Hou Y., *et al.*, Sep. Purif. Technol. 308 (2023) 122966.
- [4] Critical Raw Materials for Strategic Technologies and Sectors in the EU – A Foresight Study 2020, Publications Office of the European Union, ISBN: 978-92-76-15336-8.
- [5] Chen M., Ma X., Chen B., *et al.*, Joule 3 (11) (2019) 2622–2646.
- [6] Chakraborty S., Saha A.K., J. Energy Storage 55 (2022) 105557.
- [7] Wasesa M., Hidayat T., Andariesta D. T., *et al.*, J. Clean. Prod. 379 (2022) 134625.
- [8] Li X., Liu S., Yang J., *et al.*, Energy Storage Mater. 55 (2023) 606–630.
- [9] Jiang S., Hua H., Zhang L., *et al.*, Sci. Total Environ. 811 (2022) 152224.
- [10] European Commission, 2020. Proposal for a Regulation of the European Parliament and of the Council Concerning Batteries and Waste Batteries, Repealing Directive 2006/66/EC and Amending Regulation (EU), No. 2019/1020.
- [11] Mishra G., Jha R., Meshram A., *et al.*, J. Environ. Chem. Eng. 10 (2022) 108534.
- [12] Wei Q., Wu Y., Li S., *et al.*, Sci. Total Environ. 866 (2023) 161380.
- [13] Dunn J., Kendall A., Slattery M., Resour. Conserv. Recycl. 185 (2022) 106488.
- [14] Fan Y., Kong Y., Jiang P., *et al.*, Chem. Eng. J. 463 (2023) 142278.
- [15] Vanderburgt S., Santos R. M., Chiang Y. W. Resour. Conserv. Recycl. 189 (2023) 106733.
- [16] Latini D., Vaccari M., Lagnoni M., *et al.*, J. Power Sources 546 (2022) 231979.
- [17] Makwarimba C. P., Tang M., Peng Y., *et al.*, iScience 25 (2022) 104321.
- [18] Tian G., Yuan G., Aleksandrov A., *et al.*, Sustain. Energy Technol. Assess. 53 (2022) 102447.
- [19] Wu J., Zheng M., Liu T., *et al.*, Energy Storage Mater. 54 (2023) 120–134.
- [20] Zhang G., Yuan X., Tay C. Y., *et al.*, Sep. Purif. Technol. 314 (2023) 123555.

ECOENTER

