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THEMATIC SECTION: REWAS 2022: DEVELOPING TOMORROW'S TECHNICAL CYCLES

REWAS 2022: Developing Tomorrow's Technical Cycles

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Abstract
REWAS, a sustainability driven conference within The Minerals, Metals & Materials Society (TMS), has a long history of bringing together academia and industry to exchange and reflect on the latest technology developments in the process optimization and waste management fields. The first edition of REWAS (REcycling and WASte symposium) took place in 1999. The scope of the conference has since then broadened to include environmental sustainability, resource management and manufacturing efficiency, liaising these developments to the metallurgical industry in a broader societal and systemic context. The 2022 edition of REWAS which will be hosted at the TMS 2022 Annual Meeting & Exhibition in Anaheim, California, provides a resolute outlook towards Developing Tomorrow's Technical Cycles. Within the metals and materials industry, technical cycles refer to the ensemble of strategies and processes applied to the development of sustainable product loops with the intent to eliminate waste and instead rethink, reuse and upcycle products. The success of technical cycles requires strengthening our circular approach for product life cycle design by providing guidelines and implementation examples to the developers, designers, policy makers and business managers. REWAS promotes such strategies within a priority sector identified for Circular Economy enablement: raw materials supply and management. REWAS 2022 consists of six symposia, and abstract submissions are expected in summer 2021. Topics include recycling and sustainability within the aluminum industry, specifically on casting technologies, recovery of metals from complex products and systems, decarbonization of the metallurgical and manufacturing industry, sustainable production and development perspectives, as well as automatization and digitalization for advanced manufacturing. REWAS 2022 will also include an honorary symposium for Dr. Diran Apelian, whose contributions in metals processing, aluminum and battery recycling, sustainability, education in materials science and more have shaped the path for sustainable materials processing.

Keywords Recycling · Waste management · REWAS · Circular economy · Sustainable processes

REWAS, a sustainability driven conference within The Minerals, Metals & Materials Society (TMS), has a long history of bringing together academia and industry to exchange and reflect on the latest technology developments available to the metals and materials community. The first edition of REWAS took place in 1999, when the conference was launched as the leading international symposium for recycling technologies, water treatment, and clean technologies [1]. At that time, the abbreviation stood for REcycling and WASte symposium, but the scope of the conference has broadened to include many aspects of environmental sustainability. Since then, REWAS established itself as a major event for cross fertilization of thoughts and efforts on waste handling, pollution management, life-cycle assessment, materials availability, and recovery. In 2004 and 2008, the conference brought together diverse organizing societies across the world from academic, industrial, and governmental bodies. The 2008 edition coincided with the formation of the Materials and Society Committee of TMS that supported and promoted resource sustainability concepts within event programming and publications. Since 2013, REWAS is held every 3 years and hosted at the TMS Annual Meeting [2–5].

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Inspired by the initial scope and strengthened by its organizers, REWAS has grown to include resource management and manufacturing efficiency, liaising these developments to the metallurgical industry in a broader societal and systemic context [6–9]. In particular, the symposium puts an emphasis on product-centric approach and the links between product design, manufacturing, and recycling within the metals industry, as well as on the development and implementation of new tools and metrics for sustainability.

The 2022 edition of REWAS [10] which will be hosted at the TMS 2022 Annual Meeting & Exhibition in Anaheim, California, provides a resolute outlook toward Developing Tomorrow's Technical Cycles. Within the metals and materials industry, technical cycles refer to the ensemble of strategies and processes applied to the development of sustainable product loops with the intent to eliminate waste and instead rethink, reuse, and upcycle products. The success of technical cycles requires strengthening our circular approach for product life-cycle design, by providing guidelines and implementation examples to the developers, designers, policy makers, and business managers [12, 13]. REWAS promotes such strategies within a priority sector identified for Circular Economy (CE) enablement: raw materials supply and management. REWAS 2022 consists of six symposia, and abstract submissions are expected in summer 2021. Topics include recycling and sustainability within the aluminum industry, specifically on casting technologies, recovery of metals from complex products and systems, decarbonization of the metallurgical and manufacturing industry, sustainable production and development perspectives, as well as automatization and digitalization for advanced manufacturing. REWAS 2022 will also include the honorary symposium for Prof. Dr. Diran Apelian, whose contributions in metals processing, aluminum and battery recycling, sustainability, education in materials science and more have shaped the path for sustainable materials processing. This article details the key themes highlighted in the REWAS 2022 conference.

Diran Apelian Honorary Symposium

We are delighted this year to honor the work of Prof. Dr. Diran Apelian [11] through an honorary symposium within REWAS 2022. Apelian is widely recognized for his innovative work in metal processing and for his leadership as a researcher and educator. His research has helped establish mechanisms and fundamentals in metal processing and helped lay the foundations for significant industrial developments [12,13]. He has pioneered fundamental understanding of die casting alloys, soldering, and processing impact on Al–Si–Mg alloys [14]. Apelian's impact on metals processing has been sustained over decades from recrystallization behavior of complex quaternary alloys to friction stir processing of aluminum and ongoing contributions in the space of casting alloys. More recently, his work in the development of technologies to recover and recycle materials has become critically important for a sustainable future, including work in battery recycling [15], sustainable materials design, aluminum recycling particularly in sorting [16], dross reprocessing, and materials criticality [17]. And given the rise of data science in materials processing, Apelian again has made significant recent contributions [18]. Apelian is also strongly committed to broad, sustained impact in mentoring and education including scholarly contributions to the topic. Apelian continues to be a strong mentor today still advising students and dedicated to classroom teaching. He is also a member of the National Academy of Engineers and the National Academy of Innovators.

Apelian's contributions to and acknowledgements by the TMS community are numerous and broad in reach, too extensive to comprehensively document here. He has been a member of TMS for over 40 years serving in roles within the solidification committee in his earliest days, the aluminum committee, public and governmental affairs and as TMS president in 2008 and on the board of directors in 2013–2015. This list of accomplishments and contributions to TMS is only a subset. He not only has been a contributor both in terms of leadership positions and service but also has had a significant footprint in content dissemination and program development. He was made a TMS fellow in 2006 as well as an honorary and lifetime member of TMS in 2012. His contributions have been specifically honored by the Light Metals Division as well including being awarded the Light Metals Technology award for outstanding long-term service to the light metals industry. He served as founding editor of the *Journal of Sustainable Metallurgy* (a TMS journal) as well as on the board for Metallurgical Transactions. An honorary symposium for Dr. Apelian is particularly fitting in 2022 as it is a REWAS year and Apelian was one of the early developers of the REWAS conference associated with TMS. Apelian has made specific contributions to REWAS, kicked off by a speech he made in 2004 on material sustainability.

Decarbonizing the Materials Industry

The 2015 Paris agreement commits to limit global warming to less than 2 °C by 2050 [19]. The agreement promotes a climate resilient pathway which enables "appropriate mobilization and provision of financial resources, a new technology framework and enhanced capacity" for constructive handling of the climate crisis. In the metals, minerals and materials fields, this means concentrating efforts on carbon neutral sources of power, finding fossil fuels alternatives, optimizing energy usage, and developing negative emission technologies. Some specific technologies covered in the REWAS 2022 conference are at the forefront of innovation and are driving a global mitigation response to climate change.

Carbon capture, utilization and storage (CCUS) is the removal of CO_2 generated from fossil fuel or biomass combustion. CCUS is not a new technology and has been used for decades, mostly for enhanced oil recovery in the petroleum industry. The potential of CCUS technologies in the fight against climate change is significant. However, applicability to most industrial processes is depending on the development of economies of scale and higher efficiencies of the technologies for separation and concentration of the CO_2.

Similarly, the role of renewable and alternative energies in the manufacturing and metallurgical industry is growing. In the United States in 2018, the industrial sector accounted for over 22% of the total greenhouse emissions with 1484 MMT CO_2 equivalent released in the atmosphere [20]. Alternative energy sources for power must meet or exceed traditional fossil fuel performance while reducing greenhouse gas emissions. Biomass, solar energy, and hydropower are the main technologies serving the purpose of electrifying otherwise carbon intensive processes. Other notable renewable energy sources that will be explored at REWAS 2022 include wind and geothermal power technologies.

Traditional carbonaceous materials also carry the role of heating medium, carburizer, or reducing agent [21]. Biofuels have emerged as a suitable alternative for the replacement of fossil fuels, in that the carbon released from biomass utilization is not extracted from geological sources but instead integrated within the carbon cycle. Hydrogen is also being pursued as a suitable reagent for the reduction of iron ore to sponge DRI with commercial applications. Currently, such applications have limited use due to lower calorific values, high cost, and reactor design constraints related to operating carbon neutral energy sources. Alternatives to fossil fuels for reduction or heating in metallurgical reactors are yet gaining major momentum in steelmaking, siliceous ferroalloys, and non-ferrous processes.

Fostering existing synergies between the technologies available for decarbonization is paramount. Electrification of manufacturing processes is a key achievement in the realization of the Paris agreement goals. Increasing usage of electricity as a mean of power will require the generalization of not exclusive but complementary solutions such as renewable energies and CCUS technologies.

Digitalization and Automatization for Advanced Manufacturing

Over the last 20 years, the manufacturing and metallurgical landscape, along with much of the materials domain has been transformed by the growing interest in the use of data science to improve products and processes. This mindset has brought about the Fourth Industrial Revolution or Industry 4.0, a concept first introduced in 2011 that describes the fourth generation of industrial processes using smart technology. According to Chen et al., the extractive, materials processing, and manufacturing industry is being reshaped by the following technologies: “Cyber Physical Systems (CPS), Internet of Things (IoT), cloud computing, big data analytics, Virtual Reality (VR)/Augmented Reality (AR), intelligent robotics, Industrial Artificial Intelligence (IAI), and Additive Manufacturing (AM)” [22]. Some of the most innovative solutions for advanced materials production are being developed via automation, complex numerical simulation, and digitization. In this symposium, the specific role that these technologies play in waste management, reduction of environmental footprints and optimization of industrial materials production will be explored.

The materials community has long faced the challenge of managing large scale, heterogeneous, and difficult to measure systems. Critical innovations need to be developed to lessen the growing impact of these manufacturing processes. While the metals and materials sectors have a history of slow adaptation to new technologies, four key technology shifts are currently reshaping the industry [23]. First, availability and diversification of the data have increased, enabled by advances in sensor technologies. Second, the complexification of computational systems is not only allowing the application of new analytical tools, but also considerably shortening processing times and in turn increasing modeling capacities. Third, many traditional industrial processes involving supply chains or maintenance are now digitized, with significant effects on product quality improvement or equipment failure predictions. Finally, the reliability of automated tools utilized in manufacturing plants is increasing, enabling increased efficiency and improving safety, environment and culture in industries where difficult operating conditions are common.

Various complex phenomena inherent to the industry such as the interaction of atoms and molecules through reactions, the resulting microstructure governed by processing parameters, the influence of reactor design on transport phenomena, and the systems-implications of new technology additions are now being simulated with high fidelity models. There have been significant developments in use of digital platforms for realizing these broad systems perspectives, which the field should continue to pursue [24]. Advancing this capability will lead to gains in predictive tools used to inform on behaviors across characteristic dimensions that span from chemical species to entire factories. Improvements in process simulation have also led to the use of advanced visualization techniques, such as VR and/or AR, to improve personnel training and overall process control. Innovations in the area of digitalization have brought about the use of "digital twins", improved IAI methods for process control and automation efforts in the materials and recycling industries, all in the pursuit of improved process efficiency, safety, and profitability.

Sustainable Production and Development Perspectives

Sustainable Production and Development in the metals and materials community is a global approach to maintain a balance between economic, environmental, and societal matters while meeting an ever increasing, worldwide demand. The metallurgical sector plays a fundamental role in the realization of the 17 Sustainable Development Goals (SDG) set by the United Nations General Assembly in 2015 [25]. In particular, our community shares the responsibility to provide affordable and clean energy, enable climate action, energy storage, smart mobility, responsible production, and consumption. Sustainable approaches in the metallurgical industry require fundamentally rethinking status quos and moving forward in an innovative and collaborative way to overcome difficulties in the shift to sustainability. Key concepts explored at REWAS 2022 will include fostering multidisciplinary approaches, combining sociology, economics, engineering, and natural sciences for the realization of the SDGs via recyclable product design, life-cycle planning, policy developments, and education on global CE perspectives.

Life-cycle assessment (LCA) is one of the methodologies available to quantify environmental and societal impacts in the CE context. LCA covers the extraction, manufacturing, transportation, use, and end of life of a product. The methodology has limitations with regard to the assessment of large systems, and availability of detailed, up to date data. LCA, and in the broader sense, CE models are using digital twins to address inherent challenges for the thorough quantification of energy loss and waste generation throughout a product's life cycle [26].

Other issues affecting the enablement of the SDGs are related to poor reporting on sustainability metrics. K. P. Pucker highlights that in 2021, while the number of companies “filing corporate social responsibility (CSR) reports that use the GRI (Global Reporting Initiative) standards” is soaring, the goals of such measures have not been met due to misleading data. In particular, lack of auditing, poorly defined targets, opacity of supply chains, complexity, or misrepresentation of the data and underrepresentation of developing countries are preventing the realization of sustainable goals [27].

Properly defined and quantified metrics are paramount for the formation of alliances with other CE stakeholders. Data backed by first principles and rigorous metallurgical assessment foster vital trust and understanding from governmental bodies and the society. Cross functional groups, such as The European Training Network for the Sustainable, zero-waste valorization of critical-metal-containing industrial process residues (SOCRATES) are bringing the academic and industrial worlds together for technical advancement, training of next generations, and popularization of metallurgy concepts enabling the SDGs [25].

Recovering the Unrecoverable

Some of the most challenging and critical components to valorize covered at REWAS 2022 include energy capture and storage components (batteries, solar, and wind turbines) and electronic waste and complex scrap (rare earth magnets, PCB, multi-stream shredded residues, cables), metallurgical byproducts, residues, and slags.

Battery chemistries at the forefront of recycling development are lithium-ion batteries (LIB). Increasing the recycling rate of LIB by developing scalable recycling processes and networks is one of the greatest and most exciting challenges of the beginning of our century. LIB recycling currently takes places via two main routes, smelting of raw materials to produce an Co, Ni, Cu, and Fe alloy then treated via leaching and solvent extraction techniques or mechanical disassembly and sorting of the battery cells followed by hydrometallurgical treatment. Pyrometallurgical processing currently allows highest overall efficiency while hydrometallurgy favors selective recovery of most metals within electrode materials, separators, and other components. At a current 5% global recycling rate yet an estimated 11 Mt of EOL products available for processing by 2030 [28], the LIB sector faces the challenge of optimizing and scaling up these technologies.

Other clean energy technologies covered in this symposium are solar panels and wind turbines. Global photovoltaic (PV) panels waste is expected to reach 8 Mt by 2030 and 78 Mt by 2050 [29]. Recycling processes for PV products include physical separation, thermal treatment for silicon recovery, and a combination of wet processes for the recovery of post transition metals. Only a few commercial processing solutions are available, due to the diversity and structural complexity of the materials, Si-containing dust generation and waste organic by-product generation [30].

Management and valorization of waste electrical and electronic equipment (WEEE) are another growing challenge related to materials complexification and increased volumes generated throughout both industrialized and developing countries. Only 17.4% of the global e-waste generated in 2016 (53.6 Mt) was documented to be effectively collected and recycled [31]. Fractions that are not valorized often end up in urban dumpsite or landfills, leading to economic loss and environmental issues in some developing countries. Printed circuit boards are viewed to have the most potential for recovery with around 30% critical metals [32]. Echoing battery recycling challenges, the lack of selectivity within some high-temperature processes can complexify downstream slag valorization (especially metals with high oxygen affinity). This is pushing scrap recyclers to re-invent conditioning, comminution, and metallurgical practice applied to WEEE. While recycling of EOL electronic products is growing, reductions in waste volume via product life extension and design to recycle strategies will also be paramount for effective long-term management.

Recycling and Sustainability Within Cast Shop Technologies and Primary Aluminum Production

The 'light metals', especially aluminum and magnesium, are used for the lightweight design of transportation and aerospace structures. Changing consumption patterns have also increased the contribution of aluminum in packaging applications. The increase in aluminum containing end of life (EOL) products raises environmental concerns and increases the importance of efficient collecting, sorting, and remelting methods. Efficient recycling technologies, recyclability of complex scraps, thermal and mechanical pre-treatment approaches, efficient collecting and sorting of scraps, inert, non-carbon anodes are covered in this symposium.

The overall recycling rate for aluminum used in the automotive industry is 91% in the United States. In contrast, the Environmental Protection Agency (EPA) stated that the total recycling rate of aluminum packaging and container products was in average 34.9% in 2018 [33]. The European Aluminum Association (2020) reported a recycling rate of 90% for aluminum used in the construction and automotive industries while the recycling rate for packaging products was about 55% [34]. Smart collection and separation methods for wrought and cast alloys are one of the key factors to increase the recycling efficiencies. Opportunities not only lay with recycling efficiency. Advances in primary production include safe handling and beneficiation of waste products such as red mud and black dross, efficiency of the alloying processes. Decarbonization of approximately 0.4 tons of carbon used as anodes in the electrolysis process, inert anodes have the potential to reduce the emissions by 16% [35].

Summary

The REWAS 2022 conference will focus on the tools available to promote metallurgical and manufacturing efficiency, not only for the collection and recycling processes, but also for the development of synergies between manufacturers, recyclers, regulatory bodies, and consumers. Topics covered include carbon neutral energy sources, optimizing energy usage, increasing reactor and process efficiencies, recyclable product design as well as waste generation, digitalization, and automation opportunities in the metals, minerals, and materials fields.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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