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Tuesday May 10th

09.00 **Introduction to Cornwall**
B.A. Wills (MEI, UK)

09.15 **Introduction: The role of a technology supplier in enabling sustainability**
M.A Reuter (MEI Consultant, Outotec, Australia)

09.45 **Keynote Lecture: Towards more sustainable metal use through recycling and other technologies**
T. Norgate (CSIRO Minerals Down Under Flagship, Australia)

Resource consumption in the world is rising rapidly, driven by population growth and rising wealth. Metals will be a significant component of this increase in resource consumption due to society's almost insatiable demand for metals to provide useful services via metal-containing products. Growing concerns with regard to this escalating resource extraction and subsequent disposal have contributed to the now widely accepted concept of sustainable development. This concept requires greatly improved efficiencies in the use of resources and also major reductions in waste generation and emissions in order to break the link between economic expansion and resource consumption. Despite the increased levels of dematerialisation and recycling that are presently occurring in society, there will be an on-going need for primary metals for the foreseeable future. This supply of primary metals will be supplemented by increasing amounts of secondary metals from recycling of metal stocks in use.

In this paper, various issues relating to the sustainable production and use of metals are discussed. These issues include:

- metal reserves and resources
- sustainability indicators, including exergy
- primary metal production
  energy consumption and greenhouse gas emissions for various metals and processes
  - effect of deteriorating ore reserves – grade and liberation size
  - opportunities for reducing energy and greenhouse gas impacts – steel and aluminium
  - new technologies – biochar, dry slag granulation and waste heat recovery, direct smelting
  - other impacts – water, toxicity
- secondary metal production - recycling
  - optimum recycling rates
  - quality of recycled metal
  - design for recycling.

A number of sustainability assessment examples are also included in the paper to show that if truly sustainable outcomes for metal production and use are to be achieved, it is essential that a life cycle approach be taken.

10.15 *Technical Session 1*
Chairmen: J.S.J. van Deventer (The University of Melbourne and Zeobond, Australia) and M.K. Wedel (Chalmers University of Technology, Sweden)

10.15 **Developing a practical mechanism for incorporating sustainability principles into mineral processing plant design and operation**
G.D. Corder (SMI, University of Queensland, Australia) and S. Green (Centre for Sustainable Resource Processing, Australia)

Many organisations, including those in the resources industry have Board-level endorsed principles on sustainability. A key challenge, however, is how to systematically integrate these high-level principles into the design and operation of mineral processing plants. Current project management systems do not readily deliver the innovative solutions that are needed to address key sustainability issues, such as minimal impacts on the environment, significantly lower carbon emissions, and maintaining the societal 'licence to operate'.

In an effort to meet this challenge the Sustainable Operations framework, called SUSOP®, was conceived and developed through the Co-operative Research Centre for Sustainable Resource Processing (CSRP) in Australia. Somewhat analogous to HAZOP (Hazard and Operability Studies) which is well entrenched in the resources industry, the key aim of SUSOP® is to produce a holistic, systematic and rigorous set of processes for identifying and assessing sustainability opportunities and risks within the organising architecture of a sustainability framework.

A multi-faceted approach has been taken in the development of SUSOP®. Utilising the expertise of research and industry collaborators, drawing on the substantial body of published work on sustainable development, and most importantly undertaking 'live' case studies with the minerals industry have been critical features in enhancing SUSOP®'s development. In particular, the 'live' case studies have provided significant insights into the process of identifying and evaluating opportunities for improving an operation's contribution to sustainability and its long-term business case. Such insights have emphasised that the outcomes from a mechanism such as SUSOP® need to be integrated into current project management systems to ensure its acceptance and potential to deliver value.

This paper argues the important need for a systematic and rigorous approach for embedding sustainability principles into mineral processing plant design and operation, presents the key elements of SUSOP®, and highlights both the value that SUSOP® delivered to the case studies and how the case studies enhanced its development. In addition, the long-term aspiration for SUSOP® to become an industry standard and the reasons why such a framework will have growing importance into the future will be articulated.

10.35 **The impacts of recycling of metallic fraction from municipal solid waste: case of Helsinki metropolitan area, Finland**
T. Kuusiola (City of Vantaa Enviromental Affairs, Finland), M. Wierink and K. Heiskanen (Aalto University, Finland)

The objective of this paper was to investigate environmentally best practices to collect small household metals in the Helsinki Metropolitan Area. In order to locate the carbon reduction potential of separate collection of the metallic fraction of municipal solid waste, we carried out a carbon footprint analysis using LCI methodology on six different waste management scenarios. Four of these scenarios were residential property scenarios, where collection was organized from different sizes of residential properties and regional collections points. In one of scenarios collection was organized only using regional collection points. In addition, a zero-scenario was investigated, where all the metals are separated from the bottom ash municipal waste incineration. All separate collection scenarios include collection of metals from incineration plant's bottom ash. The modelled system consisted of a waste collection system, transportation, and different waste management alternatives, including on-site separation, separation at the waste management facility as well as metallurgical recovery of separated scrap.

The results show that recycling from residential properties is the environmentally most preferable option in terms of greenhouse gas emissions. In addition, the zero-scenario showed clearly higher carbon footprint compared to all the other scenarios. Results show also that recycling using regional collection points produces considerably less greenhouse gas benefits than recycling from residential properties.

10.55 Coffee

11.30 **Peak Minerals: assessing impacts across the life of a resource**
D. Giurco, L. Mason, T. Prior, R. Memary (University of Technology Sydney, Australia) and G. Mudd (Monash University, Australia)

Peak minerals extends the peak oil metaphor to highlight issues with initial mining of 'cheaper, more accessible and higher quality ores' before peak national production, to 'lower grade, more remote, complex and expensive ores' post-peak. This paper applies the peak minerals framework as a basis for examining the changing economic, social and environmental impacts across the life of a resource for the cases of copper and nickel in Australia. It explores the role of technology in keeping up with being able to profitably mine lower grade and more complex ores and assesses the sustainability impacts of such trajectories. Increased mining of lower grade ores is contrasted with the potential role which recycled scrap could play in meeting future demand and examines barriers and drivers under a range of future scenarios for mining and metals developed by the World Economic Forum.

11.50 **Mineral resources landscape: assessing sustainability for the case of deep sea mining**
C. Cooper and D. Giurco (University of Technology Sydney, Australia)

Attempts to pursue sustainability in the minerals sector have largely focused on reducing impacts on site. The Mineral Resources Landscape (MRL), offers an expanded conceptualisation of minerals sustainability, spanning production, consumption and recycling by connecting social, ecological, technological, economic and governance domains. By mapping benefits and impacts across local and global scales, the MRL makes explicit the disconnect between externalised impacts and the potential leverage points where they can be addressed. This paper applies the MRL to the case of deep sea mining of copper. It found that in exploring the future use of this technology to meet growing resource demand, the potential role of dematerialisation and recycling were overlooked. The paper concludes with a discussion of policy and market mechanisms to support progress toward the expanded conceptualisation of minerals sustainability.

12.10 **Drivers and barriers for effective industrial material use**
N. Pajunen, M. Wierink and K. Heiskanen (Aalto University, Finland)

The long-term goal of European Union is to become a recycling society that uses waste as a resource. The basic objectives of current EU waste policy is to prevent waste and promote re-use, recycling and recovery so as to reduce the negative environmental impact.

Environmental legislation, which includes both traditional categories such as environmental protection, pollution, environmental assessment, waste and new categories such as emissions trade, is one of the main drivers in improving material efficiency, but it may also become one of the main barriers. The most important barriers for environmental friendly innovations seem to be the cost of investment, the high risk involved in committing capital to unproven technology. Other drivers, like the corporate social responsibility, stakeholder pressure and general public pressure, will also affect the final decision. The EU encourages member states to increase the use of a combination of regulatory and economic instruments.

An important mental barrier is still the opportunity to choose. There is no obligatory need for a change. There are no sanctions for operate traditional way. That might only come from legislation.

In this work we focus on drivers and barriers for increasing material efficiency by using industrial by-products instead of raw material.

12.30 **Developing a classification system for regional resource synergies**
A. Golev and G. Corder (University of Queensland, Australia)

Even though there is a wide range of regional resource synergy projects throughout the world, categorization of synergistic connections and their related benefits is not obvious. A detailed study of existing industrial regions has resulted in a proposed classification system for regional synergies based on their economic and environmental benefits. Depending on their type and effectiveness, synergies are classified into nine groups: from business synergies (strong economic and additional ecological benefits), to better waste neutralisation and disposal (economic cost and average ecological benefits), and to symbiotic synergies (strong economic and ecological benefits).

The classification system will form part of a new Regional Resource Synergies Framework which also includes a system model to examine regional material/energy/water balances, and a systematic set of indicators for sustainability performance analysis. The application of this framework is illustrated with well-known European examples (Kalundborg, Forth Valley), as well as examples from Australian and Russian industrial regions.

12.50 Lunch

14.00 *Technical Session 2*
Chairman: D. Giurco, University of Technology Sydney, Australia

14.00 **Mitigating acid rock drainage risks while recovering low-sulphur coal from ultrafine colliery wastes using froth flotation**
C.K. Mbamba, S.T.L. Harrison, J.-P. Franzidis and J. Broadhurst (University of Cape Town, South Africa)

The South African coal processing sector generates more than 12 million tons of ultrafine slurry per annum, the majority of which is disposed of in slimes dams. These ultrafine coal wastes contain sulphide-bearing minerals, particularly pyrite, which oxidize and give rise to acid rock drainage (ARD) resulting in extensive and prolonged contamination of local ground and surface waters. Currently, the operations still emphasise an end-of-pipe approach in their management of ARD, with the focus largely on chemical and/or biological treatment techniques. In addition to the excessive cost of this approach, the generation of ARD is a long term problem (tens to hundreds of years) resulting in the challenge of achieving sustainable closure solutions within the resource lifetime.

The elimination of the threat of acid generation *before* disposal of the coal wastes would be an important development as it would have a major beneficial impact on water quality and aquatic systems in these areas and would facilitate closure solutions. The simultaneous recovery of a saleable coal product would be an added economic incentive. This paper presents the results of a collaborative investigation to develop a two-stage flotation process to produce: (i) a low-volume sulphide-rich concentrate that can be treated chemically or biologically; (ii) a benign (low sulphur) tailings, with low ARD potential compared to conventional tailings; and (iii) a coal concentrate that has added value on account of its low sulphur and ash content. Success requires integration of flotation, aqueous chemistry and mineral bioleaching expertise.

Laboratory-scale batch flotation experiments have been carried out on samples of coal utrafines, using xanthate collector to remove acid-generating sulphides, and oily collectors to float coal. Acid generating potential is determined by means of a new biokinetic test which provides enhanced results over the conventional static tests. Results indicate that a low-sulphur tailings with low ARD potential may be produced, together with a coal ultrafine concentrate stream with a low ash content. The work is being extended to confirm the results on samples from different coalfields, and to optimise the flowsheet in terms of reagents and operating conditions. The potential to upgrade the high sulphur coal stream through bio-desulphurisation is also being explored.

14.20 **The role of mineral processing technology in waste treatment and recycling**
M.K. Abd El-Rahman (CMRDI, Egypt)

The development of industries in different field based on new technology created waste materials, which causes environmental problems. These problems are air, soil, water pollution, and solid waste disposal. Waste materials could be considered as secondary resources for used in different industries if properly characterized and beneficiated to

acceptable grade and recovery. This will help in reducing the cost of waste disposal and protect the environment from pollution.

This articles aims to represent the role of mineral processing technology in waste treatments and recycling process.

Two models show the role of minerals processing in waste treatment and recycling discussed in this article. The first model concerns with the treatment of copper slag produced from copper alloying for different applications. The second model deals with recovery of carbon and molybdenum from spent Co-Mo catalyst.

14.40 **Field experimental cells to investigate the hydro-geotechnical and geochemical behaviour of surface paste disposal: design, implementation, and preliminary results**
E. Yilmaz, M. Benzaazoua (NSERC, Canada), B. Bussière (Canada Research Chair in Integrated Mine Waste Management, Canada) and S. Pouliot (Agnico-Eagle Mines Ltd, Canada)

Surface paste disposal (SPD) is a new alternative for the mining industry to store tailings at the surface. In comparison to conventional slurry tailings disposal, SPD could offer operational and environmental advantages, such as a better water management, no need for complex retaining dams, a reduced footprint of the tailings disposal area, and the possibility to use progressive reclamation. This paper describes an investigation on a large-scale field experimental cell to assess a SPD application for sulphidic mine tailings. The work addresses the effect of two disposal configurations (i.e., cemented and uncemented) on their hydro-geotechnical and geochemical behaviour. The focus will be on the implementation challenges as well as on the first results obtained. Paste tailings were deposited in thin layers (10 layers of 10 cm each one) into two experimental cells ($D \times L \times H$ = 8 m×15 m×2 m). Cement was added locally in the first layer of the cell (CC) to study its effect; the second cell (UC) is cement free. The evolution of volumetric water content θ, suction ψ, oxygen consumption, cracks, pH and elemental concentrations of the leachate for each cell were monitored during deposition and after. Preliminary results show that the CC provides slightly higher θ and smaller ψ values than the UC, probably due to its geotechnical properties dictated by the cemented layer (2 wt% of Portland cement).

15.00 **Microwave assisted pyrolysis of residual fractions of waste electrical and electronics equipment**
M. Andersson, M.K. Wedel (Chalmers University of Technology, Sweden), C. Forsgren and J. Christéen (Stena Metall AB, Sweden)

The flow of waste electrical and electronic equipment (WEEE) is large and rapidly increasing. The amount collected for recycling in Sweden 2007 was 17.3 kg per person and year. Even though WEEE is recycled today there are still valuable residues left after recycling, ending up in landfills. This paper shows how microwave pyrolysis can be a plausible way to recycle parts of the residues. Six different fractions (from light dust to particles sized 7-12 mm) of landfill waste were analyzed and pyrolysed. The process was successful producing oil, gas and a solid residue, and the mass reduction was determined as a function of process time. The solid fraction was analyzed and, as expected, found to contain an increased fraction of Cu combined with a substantial reduction of the organic part. Process temperature seemed to be independent of type of waste fraction but the mass reduction and Cu-yield varied with fraction.

15.20 Coffee

16.20 Optional Guided Coast Path Walk, ending with a beer at the Chain Locker Pub, Old Falmouth

Wednesday May 11th

09.00 **Keynote Lecture: Rethinking separation methods and sustainable uses of fine minerals**
R.A. Williams, A. Aggeli (University of Leeds, UK), R. Moreno-Atanasio (University of Newcastle, Australia), J.J. Cilliers (Imperial College, UK), N. Miles and N. Hilal (University of Nottingham, UK)

This presentation explores the prospects for re-use of fine mineral waste particulates in engineered products by recovering and separating ultra fine minerals and assembling them into new materials.

In the separation process an alternative flotation method is described using aphron systems to recover fine materials. The presentation illustrates these principles including the underlying mechanisms of bubble-particle attachment.

In the assembly process, some alternative methodologies using environmentally preferable surfactants are explored. Some examples of simple bovine serum albumins and modified peptides are suggested. Some of these systems can be triggered to be reversible, thus allowing for dis-assembly. The kinetics of such processes is modelled. The possibility of fabricating these composite mineral systems opens up ways for designing materials that can be created and later re-used by releasing them into their primary components. Models for enhancing fine particle separation for the reversible formation of such structures are explored and reviewed. The prospects and needs for development of industrially viable sustainable systems are discussed.

09.30 *Technical Session 3*
Chairmen: G.D. Corder (Sustainable Minerals Institute, Australia) and M.L. Torem (Catholic University of Rio de Janeiro, Brazil)

09.30 **A practical and rigorous methodology for integrating sustainable development principles into decision-making processes at minerals processing operations**
D. Tuazon, G.D. Corder, M.S. Powell and M. Ziemski (Sustainable Minerals Institute, Australia)

In the mining industry, high-level commitments to adopt sustainability have been made at the corporate levels of mining companies, but there continue to be problems when attempts are made to adopt these high-level sustainability aspirations and translate them into appropriate targets and methods at the more-specific operational level. The integration of sustainability principles into day-to-day minerals processing operational decision-making processes has unique challenges that are not addressed adequately by current tools and methodologies.

A proposed methodology to achieve integration of sustainability at the operational level will direct the systematic and rigorous identification and characterisation of sustainability issues in an operation. The methodology allows different approach strategies for assessment, comprehensive accounting of sustainability indicators and has the ability to identify sustainability issues which may have significant business implications that cannot be identified using traditional analysis processes.

09.50 **Recovery of gold and iodine from the effluents of semiconductor industry using activated carbon**
N.V. Nguyen (University of Science & Technology, Republic of Korea), J. Jeong, J.-c.Lee, D. Shin (KIGAM, Republic of Korea) and B.D. Pandey (National Metallurgical Laboratory, India)

This research work focused on using activated carbon to recover gold (40.5 ppm) and iodine (748 ppm) from the effluents of semiconductor industry. The effects of various process parameters such as contact time, activated carbon dose etc. were investigated for recovery of gold and iodine. The loading capacity of activated carbon for adsorption of gold and iodine was found to be 33.5 mg gold/g carbon and 835 mg iodine/g carbon. The gold was found to exist on the surface of activated carbon in two forms: ionic gold and elemental gold. The elution of gold was carried out in aqua regia by converting all metallic gold to ionic form and removing small amount of ionic gold adsorbed on the activated carbon to solution. Gold was recovered from the eluted solution by the reduction process. Iodine was then recovered from the diluted aqua regia solution by adding sodium hyposulfide ($Na_2S_2O_4$) to get precipitated iodine solid.

10.10 **Characterization of mechanical biological treatment reject aimed at packaging glass recovery for recycling**
N. Dias, M.T. Carvalho and P. Pina (Instituto Superior Técnico, Portugal)

Mechanical Biological Treatment reject is mostly composed by glass and, in much smaller proportion, other materials such as metals, ceramics and stones, representing a significant amount of glass. Nevertheless, it is commonly sent to landfill because, due to the small particle size and organic contaminations, the processes commonly used in glass recycling, like optical sorting, are inefficient in the separation of glass from contaminants.

The paper presents the results of a study undertook to characterize mechanical biological treatment reject aiming at the subsequent separation. The particle size analysis was performed and the composition of the different size fractions was determined. It was found that the size fractions over 5.6mm, representing more than 90% of the product mass, were composed by more than 80% of packaging glass. The materials density was determined. Using recent and powerful methods of image analysis the shape of particles, by material, was also evaluated.

10.30 Coffee

11.20 **The role of biohydrometallurgy in sustainable recycling of metal containing industrial wastes**
G. Lewis, S. Gaydardzhiev, D. Bastin, F. Lambert (University of Liege, Belgium) and P.-F. Bareel (Comet Traitement SA, Belgium)

Sustainability concerns are highlighting the need for increase in recycling rates of industrial wastes containing metal values in order to meet the increasing worldwide demand for metals. Metals recycling via aqueous based leaching could be a viable alternative to classical pyrometallurgical treatment (carbon foot print, investment cost etc.), especially when relatively small and low grade streams are considered. The paper aims to illustrate the feasibility of hydro and bio-hydrometallurgical processing as a down-stream route for recovery of metals from secondary resources. Leaching of non-magnetic fractions from shredder residues and automotive electric cable scraps are given as two case studies. The bioleaching efficiency is discussed taking into account the effects of material composition. The laboratory experiments have allowed to drawn some essential pros and cons of the biohydrometallurgy when applied towards metals recycling of these waste materials.

11.40 **Recycling of cadmium from hazardous waste by leaching with sulphuric acid and leaching kinetics**
M. Gharabaghi, M. Irannajad and A.R. Azadmehr (Amirkabir University of Technology, Iran)

Solid residues from hydrometallurgical zinc plants contain high concentrations of heavy metals such as zinc, cadmium and nickel, and these residues are considered as hazardous waste. Recovery of cadmium present in this waste using sulphuric acid leaching in an agitating batch reactor has been studied. It was found that the nickel extraction rate increased with increasing acid concentration, S/L ratio, stirring speed and temperature and decreasing solid-to-liquid ratio and particle size. The dissolution kinetics at 25–75 ◦C was found to follow a shrinking core model, with activation energy of 7.21 kJ/mol which is characteristic of a diffusion controlled process. The order of reaction respect to important parameters was obtained and the rate of reaction was proposed using semi-empirical equation as follows:

The results showed that the final residue can be used in other industries and recycling is a sustainable approach to this waste management.

$$1-3(1-\alpha)^{\frac{2}{3}}+2(1-\alpha)=0.63[H_2SO_4]^{1.35}(d)^{-0.238}\left(\frac{S}{L}\right)^{-0.76}\exp\left(-\frac{7.23}{RT}\right)t$$

12.00 **Preparation and evaluation of a composite material based on recycled polyethilene tereftalate and organoclay**
G. Neira Arenas and J.F. Palacios (Universidad Industrial de Santander, Colombia)

In recent years, polyethylene tereftalate (PET) has become the preferred material for the production of bottles for mineral water and soft drinks. Due to this generalized use, empty bottles of PET are also becoming a serious pollutant, making necessary to identify some effective and innovative ways to re-cycle and re-utilise this polymer. This work presents the results of the preparation and physico-chemical characterization of a composite material of PET-Organoclay, which can be used to obtain tiles and other articles for functional applications. The composite material was prepared by extrusion-injection, adding 3% p/p of organoclay minus 37 µm. Firstly, organoclay was prepared by a modifying treatment with Hexadecilamine as modifyier agent. Once the clay was ready, this was added as a reinforcement of the polymeric matrix (PET). The maximum tensile strength of the polymeric was increased from 24.02 hasta 31,84 MPa, and the Taber Index (used as an indicator of wear resistance) was increasingly higher with the increase of organoclay added to the polímero. It was proposed that the molecules of organic modifier enter the structure by substitution of Na atoms.

12.20 **Resource recovery from MSW incinerator bottom ashes**
Yongxiang Yang and Yanping Xiao (Delft University of Technology, The Netherlands)

Incineration of Municipal Solid Waste (MSW) is proved to be an efficient technology to the solution of environmental problems. Waste combustion converts the solid waste into thermal and electrical power, at the same time it generates over 20% of solid residues in the form of bottom ash and fly ash. The bottom ash consists of both inorganic mixture minerals (SiO_2, CaO, Fe_2O_3 and Al_2O_3), and significant amount of metals. In the Netherlands and most of European countries, the metal content can be as high as 15-20 wt% of the bottom ash. As a European practice, about 60% of the metal content can be recovered through physical separation, and the rest of 40% metals are still trapped into the bottom ash due to limitations of the conventional technological. This is not only a loss of the valuable raw materials, but it also causes the problems for direct use as construction materials. The ideal solution would be the recovery of all valuable metals and generation of clean and high value-added construction materials. Higher levels of materials recycling from incinerator bottom ash will solve not only various environmental challenges but also save resources of metals and construction materials.

In the present work, the research effort in bottom ash vitrification for recovering the metal contents and for producing an environmentally clean slag product is summarized. The results on refining of the recovered FeCu based alloy are presented and discussed. For a better utilization of the vitrified slag, the experimental study on the equilibrium phase relations of the related Na_2O- containing oxide system is investigated, which will provide fundamental knowledge for the application of the slag in the construction industry.

12.40 Lunch

14.00 *Technical Session 4*
Chairman: M. Benzaazoua (NSERC, Canada)

14.00 **Recycling foundry by-product in road construction: geotechnical and environmental properties**
N. Vulcano-Greullet (DREAL Bourgogne-SDD-ADEE, France), O.Yazoghli-Marzouk (CETE de Lyon-DLA-GIT, France), L. Cantegrit (CETE de Lyon-DETC-DSPES, France), L. Friteyre (CETE de Lyon-DLCF-HCF, France), J. Crosnier (DREAL Rhône- Alpes/REMIPP/MAH, France), S. Nouvion-Dupray (CETMEF/DIR, France) and A. Jullien (LCPC, France)

In industrialized country, the foundry industry produces a huge quantity of foundry sand whose management has become an environmental, economic and social imperative since they are considered as dangerous waste. On the other hand, the conservation of non renewable natural resources imposes seeking potential recycling of industrial by-products.

The availability of more than 150000 tons of foundry sand stock and its nearness to a secondary road under rehabilitation led us to lead an investigation to study the recycling feasibility of this waste within the subgrade layer of this low traffic secondary road. The new road material formulated with this industrial by-product has to satisfy geotechnical functions and environmental prescriptions in place avoiding the leaching of polluting elements.

This paper presents the chemical analysis of this by-product, as well as the formulation of a subgrade material. The environmental and eco-toxicological impacts were assessed thanks to the monitoring of an experimental site.

14.20 **Detection of system polymer tracer by UV fluorescence spectrometry to improve the recyclability of end of life product**
E. Maris and D. Froelich (Institut Arts et Metiers ParisTech Chambéry, France)

The recycling of materials from end-of life is an important issue to preserve our resources of raw materials which are more expensive and whose extraction is more impactful to the environment. But some materials are not recycled. In the case of plastics, recycling includes a grinding step leading to the production of complex mixtures. Physico-chemical processes do not allow sorting of these mixtures with a high purity. Automated sorting processes by near infrared spectroscopy are limited by the material of dark color. One proposal is to add tracers in virgin materials to allow their identification and rapid sorting in products reaching the end of life. The identification technique is the UV fluorescence spectrometry. Therefore optimizing the system polymer material / tracer / detection is based onmulticriteria approach: the reliability and speed of detection by UV fluorescence tracers added in a polymer matrix with carbon black,the relevance of an environmental impact of the tracer and the conservation of mechanical properties of the polymer added with tracers.

14.40 **An effective alternative to produce high quality aggregates from mixed construction and demolition wastes**
S.C. Angulo (Institute of Technological Research of Sao Paulo, Brazil), C. Ulsen, V.M. John and H. Kahn (University of Sao Paulo, Brazil)

In many countries construction and demolition waste (CDW) is composed by a large variety of materials including ceramic, mortar, concrete, rocks and organic contaminants. Pure concrete waste in Brazilian recycling plants is scarce since concrete pavements are not common and most reinforced concrete buildings have masonry as wall partitioning, which are not currently sorted by dismantling procedures.

This paper shows that the presence of red ceramic affects markedly the porosity of Brazilian mixed recycled aggregates and its removal by color sorting technology makes feasible the use of this material to produce concrete with moderate strength (< 50 MPa). The presence of ceramic increases the water absorption values, which is the most import property to qualify CDW aggregate according to the standards (<7%). Thus, the process to separate this phase is fundamental for the production of high quality coarse recycled aggregates. Color sorting technologies should be considered for this purpose with the clear advantage of not using water like jig processing. The sorted CDW recycled aggregates can be used to produce concrete similar to that produced with natural aggregates with 10% of cement increase.

15.00 **Separability studies on fine recycled aggregates from construction and demolition waste**
C. Ulsen, H. Kahn, G. Hawlitschek, V.M. John (University of Sao Paulo, Brazil) and S.C. Angulo (Institute of Technological Research of Sao Paulo, Brazil)

The quality of recycled aggregates produced from construction and demolition waste (CDW) is strictly related to the content of porous and low strength phases, as red ceramic particles and the patches of cement that remain attached on the natural aggregates. These phases increase the water absorption of recycled aggregates, which affects negatively the consistency and strength of the concrete. Mineral processing has been long applied to CDW recycling in order to remove cement paste attached on natural aggregates, although few authors focus on the production of recycled sand.

This study is focused on the removal of particles with high content of cement paste from natural aggregate particles (quartz/feldspar). The procedure comprehended the production of sand by tertiary impact crushing of a mixed waste followed by separability studies by density and magnetic susceptibility. Both methods were effective to reduce the content of cement paste and red ceramic particles, showing significant mass recovery (80% for density concentration and 64% for magnetic separation).

15.20 Coffee

16.15 Coaches depart for Eden Project

Thursday May 12th

09.10 **Keynote Lecture: Sustaining minerals engineering talent: a world view of supply and demand**
J.J. Cilliers (Imperial College, UK)

The demand for minerals has never been higher. Moreover, the rate at which this demand is growing is unprecedented, and expansions and new mines will be required to fulfil these growing needs. This, in turn requires a skilled engineering workforce that can develop and operate minerals extraction processes to utilise effectively more complex ores.

The International Mineral Processing Council (IMPC) has established a Commission on Mineral Processing Education to consider the global challenge of ensuring an adequate supply of well-trained mineral processing engineers. The Commission has for the past two years been collecting international information of the recent mineral process engineering supply position and with a view into the near future.

The data collected by the international Commission members are as follows:

- Undergraduate student numbers in minerals engineering
- A breakdown of their male/female ratio
- The fraction of the students from each course that enter the minerals industry
- Teaching staff numbers and age profile

This data has been collated and analysed, and initial findings will be presented. It is clear from the analysis that the supply situation is very different in different regions of the world, and that great opportunities exist for targeted recruitment into the industry to meet the future talent demand. Further, we will present a first attempt to predict this demand for minerals engineers based on the copper production rate.

09.40 *Technical Session 5*
Chairmen: M.T. Carvalho (Instituto Superior Técnico, Portugal) and O. Peyronnard (Université du Québec en Abitibi-Témiscamingue, Canada)

09.40 **Chemical, physical and microbial properties of bauxite processing residue sand as influenced by organic waste and residue mud additions**
B.E.H. Jones, R.J. Haynes (University of Queensland, Australia) and I.R. Phillips (Alcoa Ltd, Australia)

The effects of the addition of organic wastes (biosolids and poultry manure) to bauxite processing residue sand, in the presence or absence of added residue mud (applied at 10 or 20% v/v), on chemical, physical and microbial properties and on seed germination were investigated in an attempt to improve the effectiveness of revegetation of residue sand which is used to construct the outer embankments of residue storage areas. Additions of residue mud increased exchangeable Na, ESP and pH whilst additions of organic matter increased concentrations of extractable P, NH_4, K, Mg, Ca Zn, Mn and Fe. Addition of residue mud to the sand induced aggregation (and the beginnings of soil structural formation) and in the presence of added organic waste, it also increased available water holding capacity, the quantity of water held at field capacity and the size and activity of the soil microbial biomass that formed. A combination of the two additives shows great promise for effective revegetation.

10.00 **A study of pyritic sulfur abstraction from coal in H_2SO_4 solutions containing H_2O_2 and complexing agents**
E.T. Pecina et al (Universidad Autónoma de Coahuila, Mexico) and E. Orrantia (Centro de Investigación en Materiales Avanzados, Mexico)

The removal of pyritic sulfur from a Mexican sub-bituminous coal by means of hydrogen peroxide as oxidant in sulfuric acid solutions was examined. The first stage of the coal desulfurization study concerns the elucidation of the kinetic of pyrite-in-coal dissolution; the study was carried out to assess the influence of various parameters such as acid and peroxide concentrations, reaction time and temperature on the dissolution of pyrite. Kinetic models were evaluated, showing that the dissolution of pyritic sulfur follows the kinetic model of the shrinking core model, with diffusion through the solid product of the reaction as the controlling stage. In the second stage, several chemical agents were evaluated (quercetin, phosphoric acid, oxalic acid, and citric acid) to increase the pyritic sulfur abstraction. The findings reveal that the addition of quercetin (pentahydroxyflavone), enhances the elimination of pyrite from coal thus optimizing the desulfurization process.

10.20 **Biosorptive removal of cadmium from aqueous solutions using a s*treptomyces lunalinharesii* strain**
D.M. Veneu, M.L. Torem and G.A.H. Pino (Catholic University of Rio de Janeiro, Brazil)

The aim of this work was to study the fundamental aspects of a combined biosorption/bioflotation system applied to cadmium removal from aqueous solutions using a *Streptomyces lunalinharesii* strain. The main sorption conditions, such as solution pH, biomass concentration and the initial concentration of cadmium were evaluated on the metal uptake performance. The characterization of the biosorbent was carried out through zeta potential measurements, FTIR spectra and SEM images. From the sorption studies, it was observed that the highest metal removal, about 54% for a single run, took place at pH around 5.0, Biosorption studies showed that The Langmuir model fitted very well. Moreover, the maximum uptake of cadmium was 24.8 $mg.g^{-1}$. The kinetic studies showed that pseudo-second-order model properly fitted the experimental data. The integrated process biosorption-bioflotation achieved a Cd removal value around 92.1% after 20 minutes of flotation.

10.40 Coffee

11.20 **Regeneration of magnesium sulfate by decomposition**
M. Scheidema, P. Taskinen (Aalto University, Finland) and M.-L. Metsärinta (Outotec Research Centre, Finland)

Ores that are treated in hydrometallurgical processes often contain magnesium. The waste streams consist mainly of magnesium sulfate, when sulfuric acid is used for the leaching steps. Magnesium sulfate can be regenerated as SO_2 for H_2SO_4 production, and as MgO, which can be used as a neutralizing agent within the process. Decomposition of sulfates is an endothermic process; in order to decrease the energy requirement and produce reactive MgO, a reducing agent is required. This is preferably a non-carbon reducing agent, so that the formation of CO_2 in the off gas is avoided. An experimental study has been carried out on the decomposition of hydrated magnesium sulfates, under various conditions, using elemental sulfur as a reducing agent. The structure and local composition of the products is analyzed

using SEM. The results show that it is possible to decompose hydrated magnesium sulfate under given conditions very rapidly.

11.40 **Magnetite production from acid mine drainage**
R.A. Silva, C.D. Castro, C.O. Petter and I.A.H. Schneider (Universidade Federal do Rio Grande do Sul, Brazil)

The acid mine drainage (AMD) is recognized as one of the major sources of environmental damage in the coal mining industry. Because of it, a large number of companies are working in different types of treatment process with the objective to avoid the AMD to reach water resources. The active treatment of AMD involves the addition of alkaline neutralization reagents to raise pH and precipitate dissolved metals as oxides/hydroxides. Through this treatment, large volumes of sludge are generated, which requires further treatment and final disposal. Recent studies have shown that it is possible to produce magnetic particles from ferrous iron present in the AMD, allowing a reduction of about 90% of the sludge. However, the presence of other metals can interfere in the magnetite production. Therefore, the aim of this work was to study the production of magnetite by selective precipitation of iron from an AMD. The work methodology consisted in the collection and characterization of an AMD sample from the coal region of Santa Catarina (Brazil), selective precipitation of iron as a ferric hydroxide, dissolution of iron with sulfuric acid, reduction of Fe3+ to Fe2+ and conversion of ferrous hydroxide to magnetite. The results showed that it is possible to obtain magnetite crystals with great purity with an overall iron recovery from the AMD of 95%. The magnetite crystals were characterized and applied for paint production.

12.00 **Thermodynamic model for acidic ferrous sulphate from solubility data**
P.M. Kobylin, H. Sippola and P.A. Taskinen (Aalto University, Finland)

Acidic ferrous sulphate solutions are generated in large scales in hydro- and pyrometallurgical industries. Acid mine drainage has long been a significant environmental problem in coal and metal mining. Acidic ferrous sulphate solutions are also produced in steel industry and titanium dioxide production. The demand of recycling and reuse of materials has increased significantly especially in EU and dumping a neutralized deposit is not an option any more. Thus, several techniques of recycling and reuse of sulphuric acid and/or metal sulphates from the side streams are arising.

When developing alternative solutions a better understanding of the thermodynamic behaviour of $FeSO_4$–H_2SO_4–H_2O system is needed. In this study a thermodynamic model of this system is developed to yield thermodynamically consistent set of values for solubility of iron sulphate, activity of the water and mean activity coefficients of both sulphuric acid and ferrous sulphate in a wide temperature and concentration range.

12.20 **Textural characteristics of coconut shell activated carbons and their effects on gold adsorption from gold chloride solution**
W.K. Buah (University of Mines and Technology, Ghana), P.T. Williams and J. Onwudili (University of Leeds, UK)

Activated carbons with different degrees of carbon burn-off were prepared by steam activation of carbonized coconut shells. Carbonization of the shells was performed at a pyrolysis temperature of 600^{o}C and the resulting chars were activated in steam at a gasification temperature of 900^{o}C and various durations of activation. Textural characteristics of the derived activated carbons were determined and their effects on gold adsorption from an acidified gold chloride solution were studied. The surface area and porosity of the activated carbons increased with activation time up to 58.5 wt% carbon burn-off. A further increase in the burn-off resulted in loss of some structural walls between pores and consequently, a decline in the surface area and porosity of the activated carbons. The gold adsorption capacity of the derived activated carbons from the gold chloride solution was found to increase significantly with the total pore and micropore volumes of the activated carbons.

12.40 Lunch

14.00 *Technical Session 6*
Chairman: M.A. Reuter (Outotec, Australia)

14.00 **Commercialising geopolymers: revolution or reinventing the wheel?**
P. Duxson, J.L. Provis and J.S.J. van Deventer (The University of Melbourne and Zeobond, Australia)

The fundamental theory of geopolymers, alternatively termed alkali-activated cement, has been known for well over 50 years. Decades of academic and industry-based research has proven time and again that the technology is a technically viable alternative to Ordinary Portland Cement. Despite this, there has been until recently no commercially available products based on geopolymer chemistry. This presentation explores the technical barriers that stand in the way of any new material seeking to compete with Ordinary Portland Cement, with case studies detailing how these barriers can be overcome by the coupling of fundamental research with industrial application.

14.20 **Revaluing mine waste rock and its influence on cutoff grade and strip ratio**
M. Hitch (University of British Columbia, Canada)

Many mining wastes, especially those from the metal mining industry, have traditionally been treated as a matter of little or no value and in practice a cost burden. Some wastes, due to their reactivity characteristics, have emergent values, both economically and environmentally. This paper discusses aparadigm shift in waste management. Such

fundamental parameters, such as cut off grade and strip ratio, are positively impacted by the revaluation of waste rock material in this case as a substrate for CO2 sequestration and carbon offset credits it can generate. Mine rock waste can now be seen as a commodity of value similar to a by- or coproductimproving the economic performance by lowering both the cutoff grade and strip ratio of suitable mining projects.

14.40 **The use of mining waste rock as a substrate matrix for carbon capture and storage by mineral carbonation; considerations for mine planning**
M. Hitch (University of British Columbia, Canada)

Pressure on the mining sector is ever increasing with regards to greenhouse gas emissions. Carbon Capture and Storage (CCS) is one option available that could contribute to significant reductions in greenhouse gas emissions. The most stable and reliable sequestration of CO_2 is into a solid carbonate mineral. Mineral carbonation occurs naturally and has the ability to fixate CO_2 on a geologic timescale. Advances in research have shown the ability to sequester large quantities of CO_2 under elevated temperature and pressure. This has been particularly successful using MgO-rich rocks such as olivine. The present limitations regarding this method of sequestration appears to be the high cost of CO_2 avoided, largely due to the level of grinding required for mineral activation.

It is currently estimated that approximately 3 tons of MgO-rich material is required to sequester 1 ton of CO_2. The abundance of possible substrate matrix in North America alone is vast and thus merits further research. Two predominant avenues to be considered for the production of substrate material, namely mine waste rock and mine tailings, both of which offer potential benefits for applicable mining operations. The consideration of previously unwanted material could provide additional revenues through the offset of carbon credits and the potential generation of an additional saleable carbonate product.

For the successful addition of using waste rock as a substrate matrix for mineral carbonation into a mine plan, a number of implications and stages must be considered. Initial laboratory scale tests are essential to determine the capacity for CO_2 fixation. This is important to confirm the ability of the substrate matrix to sequester CO_2, however a cheap repeatable method of determining the sequestration potential (SP) of the rocks from drillhole data is needed. The geostatistical behavior of SP values is unknown and may have significant implications on its inclusion into mine planning and scheduling. The successful generation of SP values and understanding of their geostatistical representation could lead to each block of waste rock within a mines economic block model gaining an SP value. The ability of viewing previously considered waste rock as a series of blocks with attributed SP values allows incorporation into mine planning and scheduling. Careful consideration to cost, infrastructure, CO_2 source, processing, quality of carbonate product and storage implications would undoubtedly be required for CO_2 sequestration by mineral carbonation feasibility.

15.00 **Alternative by-product based binders in cemented mine backfill: recipes optimization using the Taguchi Method**
O. Peyronnard and M. Benzaazoua (Université du Québec en Abitibi-Témiscamingue, Canada)

In this work, 5 industrial by-products (glass, copper slag, wood ash, anhydrite and CKD) were used to create low cost binders to be used in mine backfill. The Taguchi method was successfully used to optimize binders recipes targeting a maximization of the mechanical strength developed after 7, 28 and 91 days of curing. This method was chosen because it allows the optimization of 4 parameters (by-product content, activator, GGBS and CKD contents), each having 3 possible values, with only 9 experiments.

It is shown that the mechanical strength is linked to the blast-furnace slag content and that, using anhydrite, CKD or increasing the by-product content allows an acceleration of the strength development. The optimized binders' high performances were confirmed by validation experiments. Because of its several advantages (reduction of number of experiments, possibility of studying qualitative and quantitative parameters...), the Taguchi method should be generalized for pastefill optimization purposes.

15.20 **Extraction of lithium from micaceous waste from china clay production**
E. Siame and R.D. Pascoe (Camborne School of Mines, UK)

The granites of South-West England are a potential source of lithium which is generally found within mica minerals such as zinnwaldite and polylithionite. These minerals are concentrated in the central and western end of the St Austell granite. When kaolin extraction occurs in these areas a mica-rich waste product is produced which is currently disposed of in tailings lagoons. In this study a tailings sample containing 0.84% Li_2O was upgraded by a combination of froth flotation, using dodecylamine as the collector, and wet high intensity magnetic separation to 2.07% Li_2O. The concentrate was then roasted with various additives, including gypsum and sodium sulphate, over a range of temperatures. The resulting sinters were then pulverised before being leached with water at 85°C. Analysis of the sintered product by XRD revealed that the water-soluble sulfates, $KLiSO_4$ and $Li_2KNa(SO_4)_2$, were produced under specific conditions. A maximum lithium extraction of approximately 84% was obtained using gypsum at 1050°C. Sodium sulphate produced a superior lithium extraction of up to 97% Li at 850°C. In all cases iron extraction from the sinter was very low.

Using a series of leach experiments with the sodium sulphate sinter it was shown that a Li_2CO_3 product could be produced solution by precipitation with sodium carbonate.

15.40 Closing remarks : M.A. Reuter (Outotec, Australia) and J. Wills (MEI, UK)

16.00 Coffee

Posters

Integrated mine tailings management: possibilities for coal tailing deposits in Santa Catarina, Brazil
J.R.A. Filho, B. Firpo, A.V. Colling, E.M. Vigânico, C.H. Schneider and I.A.H. Schneider (Universidade Federal do Rio Grande do Sul, Brazil)

Brazilian run-of-mine coals (ROM) contain high levels of impurities (rock minerals and pyrite), requiring concentration procedures. The coal tailing deposits demand large physical area, change the topography and generate the acid mine drainage (AMD). It is estimated that more than 300 millions tonnes of coal tailings exists in the south of Brazil, generating environmental impacts and economic costs. This work characterizes a typical coal tailing deposit, seeking the separation of three fractions for future reuse: (a) a fraction of low density; (b) a fraction of intermediate density; and (c) a fraction of high density. The characterization studies included particle size analysis, dense medium studies, XRD, acid acid-base accounting tests, and determination of ash and total sulphur. The results showed that 67% of the material is composed by coarse particles, 14% by fine particles and 19% by the slurry from the settling ponds. It is possible, by gravimetric concentration, to recover 34.2% of the material for energy generation and 9.2% of the material as a pyrite rich concentrate. The remaining material, with intermediate density, has a lower acid generation potential and can be ground and prepared to find applications in civil engineering (as aggregate) and agriculture (as rocks for crops). This approach brings a new outlook to tailings management in the Brazilian coal-based industries. The study showed that it is possible to decrease or even eliminate the environmental liabilities of coal tailing deposits by means of Research, Development and Innovation (R&D&I). The coal companies can diversify their production, and, even after decommission of the mining exploration, continues their activities processing the coal wastes.

Mineral transformations induced by high energy mechanical milling of refractory gold ores
G. Neira Arenas, O.I. Delgado-Ramírez and A.A. Mendoza Prada (Universidad Industrial de Santander, Colombia)

The complex refractory nature of gold ores is a common hindrance for the improvement of small scale mining operations carried out in the mining district of the Santander Province in Colombia, and it is also associated to a high risk of pollution, not only due to the excessive use of cyanide but also for the dissolution of accessory minerals containing potentially harmful elements for both biota and human beings. In this work, refractory gold ore samples from the district were mechanically activated by high energy milling for different periods of time, in the presence and absence of lime. XRD, FT-IR, TGA, and settling analysis were carried out in order to determine the effects of the activation process on the ore, and its relation to the mineral cyanidation behaviour. The results showed important physical, chemical and crystallographic changes induced by the milling, which have a strong influence over important leaching factors. The observed changes include amorphization of jarosite and orthoclase, disappearing of muscovite, and recristallization of pyrite from triclinic to cubic. On the other hand, the experimental evidence suggested that lime addition seems to delay the amorphization of some phases.

Mechanical milling activation as a pre-treatment for the cyanidation of refractory gold ores
G. Neira Arenas, O.I. Delgado-Ramírez and A.A. Mendoza Prada (Universidad Industrial de Santander, Colombia)

A highly refractory concentrate of gold ore (36 gAu/ton) from the mining district of California in the Santander Province (Colombia), was mechanically activated by milling in an attritor mill for several periods of time and different pH conditions, and then leached for 48 hours by conventional cyanidation. Diagnostic leaching analysis of the ore revealed a 52% of gold associated to pyrite-type species, and an additional 13% associated to other sulfides, carbonates and iron hydroxide. The cyanidation results showed that high energy milling of the ore significantly increases the dissolution of gold, probably due to the increase in chemical reactivity. After 10 hours milling in the presence of lime, 69,85% of gold was dissolved, which represents a dissolution increase of approximately 30% compared to the ore without milling. Milling times higher than 10 hours did not show effective increases in gold dissolution, probably due to some possible transformations of mineral species, or release of cyanide-consuming elements.

Potential production of ferric sulphate from the tailings of coal mining in Brazil
J.C.S. S. Menezes, I.S. Arce and I.A.H. Schneider (Universidade Federal do Rio Grande do Sul, Brazil)

Recent studies show the possibility of producing a coagulant based on ferric sulphate for the treatment of water and effluents from coal tailings. The objective of this study was to evaluate the potential and quality of ferric sulphate produced considering different sources of coal tailings, namely: (a) obtained by reject coal jig from the bottom Jacuí of Rio Grande do Sul (b) obtained by reject coal jig layer of Clay White of Santa Catarina, (c) reject rebeneficiado a jig for the concentration of pyrite layer Bonito de Santa Catarina, (d) reject rebeneficiado a jig for the concentration of pyrite mine of Cambuí, Paraná . The results show that all tailings studied showed potential for production of the

coagulant. It was concluded that the treatment of waste from coal increasing the concentration of pyrite allowed obtain a ferric sulphate of best quality.

The influence of crushing on the properties of recycled aggregates from concrete waste

C. Ulsen, E. Tseng, H. Kahn, J.T. Balbo (University of Sao Paulo, Brazil) and S.C. Angulo (Institute of Technological Research of Sao Paulo, Brazil)

The properties of recycled aggregates are directly related to the presence of porous materials and the processing technology. The crushing stages is fundamental on the reduction of the content of fragile and porous adhered cement paste on natural quartz/feldspar aggregates; however the increase of crushing steps leads to the reduction of the aggregates top size and noticeably interferes on the reclamation ratios of coarse fraction.

This paper discusses the influence of the crushing mechanism and number of stages on the removal of cement paste attached on coarse CDW recycled aggregates. A representative sample of crushed concrete was obtained from a recycling plant; the secondary crushing was performed on jaw and impact crushers in order to compare the quality of the recycled aggregates.

The products, before and after the second stage of crushing, were characterized according to the weight distribution in density class by sink-float assay, the content of cement paste, water absorption, Los Angeles abrasion index and particles shape. Crushing reduces the variability of particles physical properties (density and porosity) of the CDW recycled aggregates. It reduces overall porosity and it increases overall density. For coarse aggregates, the differences on particle shape and the reduction of cement paste content between crushing mechanisms are subtle.

Utilization of ashes from the leather shaving incineration as a source of chromium for the production of HC-FeCr alloy

C.R. Alves, N.C. Heck and I.A.H. Schneider (Universidade Federal do Rio Grande do Sul, Brazil)

The tanning industry, during the leather tanning, produces shavings that, because of the method used, have chromium in its chemical composition. Volume reduction and energy utilization can be achieved by shavings incineration. The ashes from leather shaving incinerations contain chromium oxide (Cr_2O_3) in an amount of 50 to 60 wt%. The aim of this work is to show that the recycling of the metal contained in leather shaving *ashes* is possible as raw material for stainless steel production, relieving the environment of a dangerous residue. The elaboration of a ferroalloy with similar characteristics of the commercial HC-FeCr ferroalloy was investigated at the laboratory scale. Prior, a thermodynamic analysis was carried out, simulating the process of chromium oxide reduction in order to provide the basis and the most favorable conditions for the experiments. At the laboratory level, it was demonstrated that is viable the reutilization of chromium bearing ashes from the incineration of leather shavings for the production of HC-FeCr.