Paperchain Project: Establishing a New Circular Economy Model between the Mining Sector and the Pulp & Paper Industry to Prevent Acid Mine Drainage

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Abstract European Pulp and Paper Industry (PPI) generates 11 million tonnes of waste yearly. Most of them are burnt for energy recovery or used for landspreading, but around 1.5 million tonnes are still disposed. If managed in a sustainable manner, they can become a valuable secondary raw material for other resource intensive industries. PAPERCHAIN, a research and innovation project funded by the European Commission, addresses this potential resource to demonstrate their technical, economic, social and environmental feasibility from the Circular Economy perspective. In detail, Green Liquor Dregs are presented as an example of cooperation between the PPI and the mining sector.

Key words waste valorisation, industrial symbiosis, alkaline amendments, covers

Introduction

According to the Confederation of EU Paper Industries (CEPI), Pulp and Paper Industry (PPI) waste streams have shown a great potential as feedstock for the production of high value products in other industries, paper (fibres) or energy conversion. Nowadays, 55% of this waste is burnt for energy production, land application accounts to 15%, and exploitation of residues in other industries to 10% (Deviatkin et al. 2015). However, 1.65 million tonnes of waste generated by the Pulp and Paper industry (15% of the total waste) are still disposed to landfills. In addition, the valorisation of this waste has also a direct impact in landfilling itself due to the generation of ashes. In fact, it triggers that most of the landfilled waste correspond with inorganic wastes (causticizing residuals and ashes) which are currently used as cement raw meal, and to a lesser extent, as amendment in forestry.

Furthermore, Europe is nowadays facing the challenge of resource scarcity and more efficient use. If managed in a sustainable manner, PPI waste can become a valuable raw material for other resource intensive industries such as the construction (i.e 5,4 billion tonnes of raw material consumption in Europe) or the chemical industry (1 billion tonnes). Moreover, mining industry waste generation is estimated at up to 20.000 million tons of solid waste yearly (Lottermoser 2007). A relevant part of this waste needs to be kept in environmental safety conditions, which in turn implies additional use of resources (e.g borrow materials).

A major potential long-term environmental effect of mining is the formation of acid rock drainage (ARD) in sulphide-bearing mine waste, which can last for hundreds or even thousands of years. The common ways to deal with ARD are either to prevent the oxidation of sulphide minerals or to mitigate the negative effect of ARD, buffering the acidity and immobilising metal ions. Waste rock is commonly disposed in large landfills in the vicinity of mines and a common method is to cover mine waste deposits to limit water and oxygen infiltration to the waste or to lime the collected ARD in sedimentation ponds, generating huge amounts of potentially toxic sludge. When dry covers are constructed on the waste rock piles, they usually consist of engineered barriers designed also for dust and erosion control; contaminant release control and provision of a growth medium for vegetation. Engineered barriers consist usually multilayer constructions built of borrow materials available on site, mainly granular and clayey soils.

In the Nordic mining area, glacial till is the most common borrow material. Glacial till is granular, fine grained and has medium to low permeability. Clayey till has sufficient water retention capacity, which makes it useful for being used in mine covers in order to avoid oxygen infiltration, However, clayey till is a limited resource in the sub-arctic environment, implying often transport over long distances of huge amount of construction material. There is therefore an interest to improve material with high hydraulic conductivity. Alternatives to virgin earthen materials are quite scarce and mainly related with the modification of soil natural properties (clay, till, silt) by adding amendments to improve their waterproofing properties, their mechanical resistance or to provide additional ARD inhibition properties. Some amendments based on recycled waste have been tested in mining projects along the last two decades. Some examples include phosphate refuse to neutralize acidity, mixtures of high alkalinity waste (cement kiln dust, coal fly ash) with soils to produce high alkaline leachates and organic-based waste such as lignocellulosic-based materials (wood chips and wastes, sewage sludge, straw, paper mill sludge) for oxygen consuming barriers (SENES 1994; Haug and Pauls 2001).

Meanwhile, Green Liquor Dregs (GLDs) are the largest waste fraction retrieved in the chemical recovery cycle at the sulphate pulp mills. Approximately 240.000 tonnes are landfilled solely in Sweden each year because their only current relevant application is as final landfill cover layers.

The mining sector can benefit from GLDs as alternative material for covers to reduce raw material consumption in their reclamation projects (Maurice et al. 2010). GLD is a waste classified as non-hazardous which consists mainly of $CaCO_3$, Na_2CO_3, Na_2S and insoluble solids. They have a low hydraulic conductivity (10^{-7}-10^{-9} m/s) and highly alkalinity (pH 11-13) which opens the possibility for their use as soil cover. Blending GLDs along with glacial till will produce a new engineered barrier with reduced thickness thanks to its improved sealing and water retention capacity, contributing to avoid water and oxygen ingress. Furthermore, the high alkalinity of GLDs provides this cover with an important reactivity to neutralize any acid leachate and to keep alkaline oxidation conditions, deploying three functions at the same time (Jia et al. 2016). Finally, GLDs could be also used to chemically neutralize ARD; Covers aim at preventing the formation of ARD but other strategies are possible to mitigate its negative effects by using GLD's (Maurice et al. 2010). Co-disposal with waste rock, injection in slurry and mixing in ARD are alternatives to use GLDs for mitigation of acidity and reduction of metal mobility.

Luleå University of Technology (LTU) has been conducted an extensive research for the last 7 years in cooperation with SP-Processum, to develop an innovative engineered barrier based on improving properties of glacial till by adding GLDs. The research cooperation has included laboratory characterisation, mixing experiments and pilot test areas as shown in fig. 1 (Maurice and Mácsik 2016).

Figure 1 *Mixing experiment and construction of a pilot sealing layer, Boden, Sweden 2014.*

At the same time as local till material would become available for remediation of mine waste deposits, the PPI could find a new market niche to valorise a waste product which is currently disposed of, solving two waste problems at the same time, from a Circular Economy perspective.

The laboratory and field-tests conducted by LTU and partners demonstrate the performance of GLDs-till blends. However, there is a lack of data about the long-term performance which impede the market-uptake. Moreover, the lack of previous applications in real environments leads to too conservative cover thickness which is directly related with economic feasibility. In addition, although some handling procedures for blending have been developed at semi-industrial scale, there is still a need for establishing feasible handling and blending procedures at industrial scale.

Objectives of the project

PAPERCHAIN´s target is to deploy five novel circular economy models centred in the valorisation of the waste streams generated by the PPI as secondary raw material for a number of resource intensive sectors: construction, chemical and mining. The project aims at unlocking the potential of a resource efficient model based on industrial symbiosis which will demonstrate the potential of the major non-hazardous waste streams generated by the PPI (i.e. green liquor dregs, grits, lime mud, paper sludge fly ash, deinking paper and fibre sludge) as valuable secondary raw material (tab. 1).

PAPERCHAIN tackles the valorisation of almost the totality of these PPI waste streams although the project focuses on those whose current fate is mainly landfilling, such as the causticizing residuals, and those which are produced in major quantities, such as sludge or ashes (fig. 2).

Table 1 *Characteristics and composition of the addressed waste streams.*

Waste	Provenance and composition	Current fate	Paperchain
GLDs	Nonreactive, insoluble materials recovered from the furnace. Burnt lignin, calcium, sodium and magnesium carbonates and sulphates	Landfilling (95 %)	Asphalt fillers. Soil covers.
Lime mud	Precipitated along the causticizing reaction. It consists of calcium carbonate and water	Burnt in lime kiln and landfilled	Concrete filler
Slaker grits	Rejects from the lime kiln and limestone fragments precipitated during the causticizing reactions. Contain sodium and aluminium salts	91% currently landfilled	Aggregates
Fibre sludge	Generated in wastewater treatment plants. Includes wood fibres, kaolin, $CaCO_3$ and TiO_2	Landfilled (50%), fuel (25 %), LS.	Ethanol for chemicals
De-inking paper sludge	Composed of short fibres, coatings, fillers, ink particles and additives	Landfilled (40%) and fuel (35 %)	Slope stabilisation
Waste paper ash	Produced from the burning of different waste in the recycling-based mills	Landfilled (≈100%)	Road binders

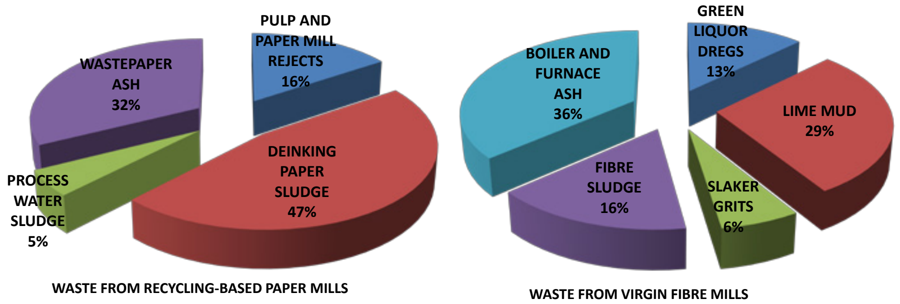

Figure 2 *Distribution of the waste generation in the Pulp and Paper Industry. Modified from Suhr et al. 2015, Bird and Talbert 2008*

Mining is one of the key addressed sectors and the objective is to go beyond the state of the art in relation to performance, as well as to develop guidance to guarantee both technical and economic feasibility. Firstly, the project tries to involve the whole value chain in the projected pilot in Sweden (waste generators, waste managers, end-users and academia) showing the environmental benefits and the new business opportunities. The pilot will use more than 3000 tonnes of GLDs which implies savings of 270.000 € in landfill fees and borrow materials, as well as 12.9 tonnes of CO_2eq in a 10 Ha reclamation project.

Furthermore, this demonstration will be the starting point to replicate the model throughout Europe. The most relevant European metallic mining regions are located in Sweden, Finland, Poland, Spain or Portugal and these regions achieve more than 70% of the European pulp production. This is the starting point for setting up a new Circular Economy Model to manage AMD with pulp waste. Replication of demonstrated technologies will take place over the medium and long-term and will be based on the dissemination and communication activities of the success stories of the pilot, starting with the activity of the project´s partners. At this stage, 60.000 tonnes of GLDs are expected to be valorised in a two years scenario solely in Sweden, which implies savings of 5.3M€ and 258 tonnes of GHG emissions.

Methodology

The project is structured in three phases:

The first phase will set the reference framework for the development of the circular models surrounding the PPI. It includes the characterization of wastes to adapt them to the target industrial applications' requirements and the identification of the existing supply structures for the provision of secondary raw materials and preliminary business opportunities assessment.

The second phase will deal with the demonstration activities. The waste valorisation structure will be designed for each industrial sector and the treatment processes defined either at production stage (i.e within the PPI) or afterwards (i.e waste manager). Logistics and financial aspects will be addressed. Once the supply structure is ready, five large scale demonstrations will be carried out to demonstrate the circular business models (fig. 3).

The last stage will involve the market uptake activities and replication of the solutions. It will comprise the sustainability analysis of the circular models and the evaluation of the circularity of the products. The environmental performance of the developed solutions including the reactive soil covers will be evaluated by means of the EU Environmental Technology Verification programme (ETV). Finally, the main project outcomes will be communicated and promoted to the general public to encourage engagement.

Mining Circular Case: GLDs as reactive cover

Project´s main objective is to demonstrate and optimize the use of GLDs in sealing layers for mine waste deposits. Performed research has shown the advantage of using GLDs ((Mäkitalo et al. 2015); however, laboratory and pilot experiments do not permit optimize full-scale production. This pilot will get evidence to propose an efficient method to produce and built GLDs-based sealing layers.

Based on previous results, guidance for characterization and definition of mixing recipes has been developed along with a method for mixing and compacting the sealing layers (Maurice

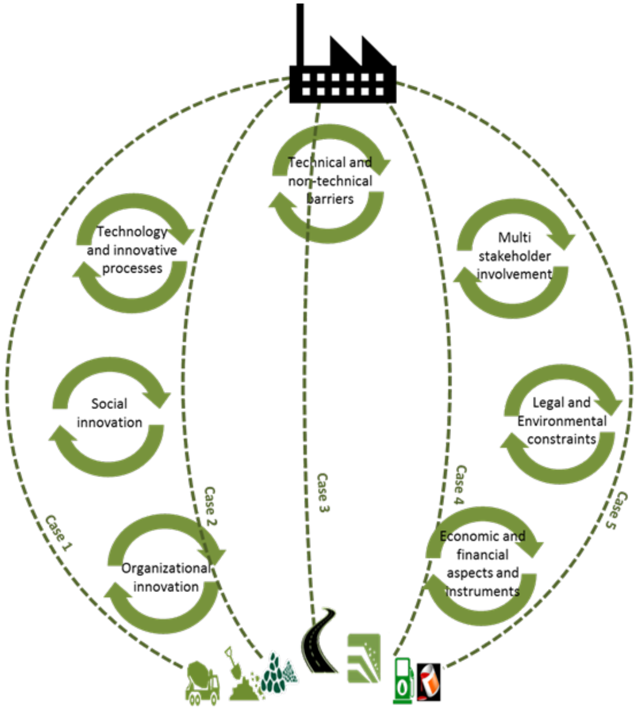

Figure 3 *Project concepts, proposed methodology and addressed topics.*

and Mácsik 2016).. This guidance can be tested in a real environment, a 4.4 Ha waste rock landfill in Northern Sweden operated by Boliden to be carried out in summer of 2017.

Given its innovative character, no information is available on the robustness of the sealing layer for its sizing, so that, a large safety factor has been used for the construction work regarding the mixing process, the compaction, and the thickness, in order not to take any environmental risk. As a consequence, the solution is oversized and has to be optimized by reducing safety factors to reach the market. PAPERCHAIN project will carry out the following activities:

Pilot monitoring at the mine site provided by Boliden Mineral, where a GLDs/till mixture will be used as sealing layer. The effect of aging on the barrier function of the layer will be studied during the first two years of the project to identify uncertainties about the technology. The monitoring will result in the definition of new specifications for the demo, including the optimisation of the layer thickness.

Construction of 500 m² demonstrator to optimise the cover construction. The demonstration comprises three steps; i) optimisation of mixing using e.g. in-situ mixers, ii) comparison of different compactors and iii) assessment of the barrier function of sealing layers (0.2-0,5 m) and protective layer (0.3 – 1.5 m) with varying thickness.

Assessment and follow-up of the demonstration site to measure, water content, oxygen transport and temperature within the layers. The effect of the leachate (percolating precipitation) on the underlying mine waste and the recipient, monitoring those parameters (metals and anions) according to regional laws. The conclusions of the assessment will serve to update the guidance for construction of sealing layer for mine waste deposits.

Conclusions

The PPI is in the way of achieving the zero-waste target, although some waste streams are still disposed of, especially those inorganic fractions with no interest for energy recovery or agricultural beneficiation. The transformation of these wastes into valuable secondary raw material can be secured by the establishment of Circular Economy models with other sectors based on research and innovation projects along with the initial support of public authorities.

PAPERCHAIN project tries to develop and demonstrate the profit of PPI wastes for different resource intensive industries, including mining. Planned activities include the demonstration of both, technical and environmental performance of GLDs in soil covers, and also the economic feasibility by means of assessing the quality, availability, logistics, workability and durability of this material and the projected solution.

Involvement of all the actors along the value chain with the support of academia and public authorities is a key aspect for the success of the project: Value creation, sustainability and replication. In this sense, the geographical correlation between PPI and main European mining districts as well as other mining relevant countries with forest industries, makes these technologies promisingly replicable.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 730305.

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