*Bio sludge is a waste that is produced in large amounts at the pulp and paper industry waste water treatment. It is wet and has no obvious advantages, therefore few recycling methods are in praxis but focus is on disposal. Common disposal methods are incineration and composting. In Sweden and Norway about half of the sludge is incinerated, but in Finland almost all of it is incinerated. Landfilling of the sludge is common in Chile where half the sludge is landfilled and the other half is incinerated.*

*Efficient use of material and energy is crucial for future more sustainable industry practices. This is true for primary products and commercial available energy but also for material that today is regarded as waste. The pulp and paper industry is subjected to a shift in consumer behavior initiated by modern information technology that results in lower demand for newspapers. In the future there are reasons to expect increased competition from new producers in countries where the productivity of the forests are higher and thereby the production costs is lower. These two aspects forces the pulp and paper industry in the Scandinavian countries to optimize the efficiency of their mills and to seek revenues from new types of products.*

*Biomass waste in general could be recycled for its energy content or after conversion/extraction as a chemical product or a solid material. Different forces like legislation, market demand and scientific innovations exert a push or pull towards different paths of recycling. They may either cooperate or counteract each other and the sum of their impact may favor one of these paths.*

*Some possible paths of recycling inspired by industrial symbiosis will be presented and the maturity of these technologies assessed. The sludge's content of heavy metals have been compared to limit values in Swedish national regulation and standards.*

*The content of metals in the sludge exceed some of the current limit values and could in a greater extent exceed the future limit values if they will be lower than today. Therefore direct application of the sludge can only be a short term solution.*

*Most treatment methods produce either a liquid or solid residue and the metals could be concentrated in any of these so the metals in the residue must be assessed regardless of what technology is used. To maximize the usefulness of the sludge it is essential to assume that the problem with the metals can be solved.*

*Production of bricks and glass stabilizes the metals but the resources are then locked in a matrix which make them to a lesser extent available for use.*

*The production of SCP and a lead adsorber are two alternatives that is regarded both circular and relative mature. These two should be assessed according to the LCA-method together with incineration combined with improved dewatering.*

# 1 INTRODUCTION

The evolving bio economy is an important contribution to sustainable businesses. Its focus is on using renewable resources and shifting out non-renewables. The pulp and paper industry is an important user of the large quantities of renewable resources we have in our forests. During processing of the timber into pulp, large volumes of water are used and subsequently treated prior to flushing into the recipient. The organic matter and nutrients removed from the water are valuable resources but unfortunately are regarded as waste.

Few recycling methods are being practised; the focus is instead on disposal. Common disposal methods are incineration and composting. The purpose of this work is to find better methods of using this resource than those currently being practised.

# 2 METHOD

A literature review has been carried out to compile the current research on different ways of using the sludge and the different types of benefits derived from those uses. Its chemical content has also been compiled, along with the consequences for the appropriateness of different recycling routes assessed. The degree of maturity of the available technologies has been assessed. A Swedish waste-handling company has been asked to answer how they assess the degree of circularity of the solutions found in the literature study. Finally, a qualitative discussion about the sludge's inherent properties and the appropriate recycling methods is presented, to make it possible to choose the technologies on which to apply a comprehensive life cycle assessment. This LCA is the next step in this project and is not presented in this article.

### LITERATURE STUDY

In the research community, sludge has been the focus of a huge number of scientific articles. In order to get a complete picture of how many alternative methods there are for recycling bio sludge and what can be done with it, a literature study has carried out.

There are fewer articles specifically about bio sludge, or secondary sludge, as it is also called. Therefore we will also include primary sludge or fibre sludge. Fibre sludge comes from the clarifier step previous to the bio treatment. It differs from bio sludge in that it has a higher fibre content. But because it comes from the same source, it can be relevant to widening this literature study in order to provide a broader knowledge base and not miss any possibilities.

Even though sludge from municipal wastewater treatment plants (WWTP) can differ from bio sludge from the pulp and paper industry, some properties can be comparable. The heavy metal content does not differ so much between these two types of sludge, but the nutrient content in bio sludge is lower (Henriksson et al., 2012, p. 4). Therefore municipal sewage sludge has also been included.

### RELEVANT LIMIT VALUES

In order to assess the usability of the sludge one can compare the metal content to the corresponding limit values in certification standards of different land applications. Even if these criteria don't apply to the sludge as such, but for a material derived from sludge, it does help the assessment.

The criteria used are from following sources:

- European Union Ecolabel award for soil improvers (The Commission of the European Communities, 2006, para. 1.2)
- SPCR 120 Certification rules for digestate from bio-waste by the quality assurance system of Swedish Waste Management, SP Technical Research Institute of Sweden (2015, p. 14)
- SPCR 148 Certification of soil for agricultural and civil engineering purposes by P-marking, SP Technical Research Institute of Sweden (2006 Appendix 2, 3, 4, 5)
- SPCR 152 Certification of compost from bio-waste by the quality assurance system of Swedish Waste Management, SP Technical Research Institute of Sweden (2014, p. 13)
- SPCR 155 Certification of liming products for acid lakes and wetlands by P-marking, SP Technical Research Institute of Sweden (2011 Appendix 2, p. 3)
- The Swedish forest agency's recommendations for content of metals in ash for forest application (Emilsson, 2012, p. 22)
- Swedish legislation for sludge use on farmland (*Förordning (1998:944) om förbud m.m. i vissa fall i samband med hantering, införsel och utförsel av kemiska produkter*, 1998)

### Degree of maturity

The concept of Technology Readiness Level (TRL) was first developed by NASA during the 1970s and 1980s (*The TRL Scale as a Research & Innovation Policy Tool, EARTO Recommendations*, 2014, p. 3). This is a complex tool to apply and in order to use it on this number of methods it must be simplified. A coarse assessment based on that of the U.S. Department of Energy (DOE) will be used instead (*Technology Readiness Assessment Guide*, 2011, fig. 5).

### Degree of circularity

Circular economy is a concept that has evolved during recent years. It is not something completely new but is based on the insight that just slowing down the rate the resource flow through society is not enough. The linear flow of resources from well to the landfill must instead be bent into a loop ("The circular model - an overview," 2013).

Thirteen specialists and managers in one of the major Swedish waste companies have assessed how they perceive the degree of circularity of the recycling options found in the literature study. They have given a value (1–4) to each of the technologies. A value of 4 represents the most circular solution and 1 represents the least circular solution.

## 3 Results

### Current handling of the sludge, and sludge properties

In Sweden and Norway about half of the sludge is incinerated, but in Finland almost all of it is incinerated. Landfilling of the sludge is common in Chile where half the sludge is landfilled and the other half is incinerated (Sivard et al., 2013, p. 22).

The sludge from pulp production contains the non-usable fractions of the tree and the micro-organisms that feed on it in the water treatment process. Organic elements constitute a large part of the material. The sludge constituents are accounted for in Figure 1 below (Meyer and Edwards, 2014, p. 4).

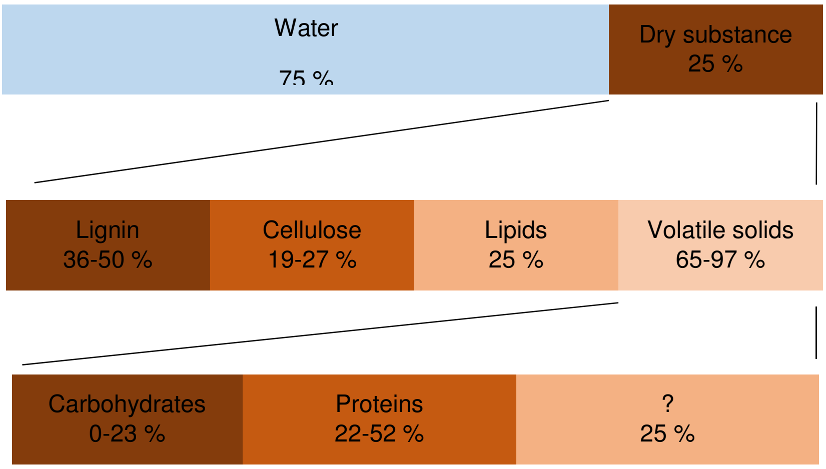


*Figure 1 Characterisation of bio sludge I*

The most important elements are presented In Table 1 (Gyllenhammar et al., 2003, pp. 28, 30, 33, 34). They are average values of biosludges from six sulphate mills. Some problematic metals have also been analysed and their values are shown. The sludges analysed are from two sulphate mills (Norgren, 2012); (Oden, 2012).

Table 1 Content of bio sludge I

| **Para-meter** | **Value (bio sludge) (max/min)** | **Unit** | **Para-meter** | **Value (bio sludge)** | **Unit** |
|---|---|---|---|---|---|
| C | 53 | % maf | Kjeldahl-N | 4,4 | % maf |
| H | 7 | % maf | K | 1545 | mg/kg DS |
| O | 33,8 | % maf | P | 4785 | mg/kg DS |
| S | 1,8 | % maf | Humidity | 75 | % |
| Heating value | 19,9 (18-22,5) | MJ/kg DS, ash free | Ash content | 27 | % DS |
| Metals exceeding their limits | | | | | |
| Co | 28,5 | mg/kg DS | Hg | 0,15 | mg/kg DS |
| Zn | 148 | mg/kg DS | Cd | 0,5 | mg/kg DS |
| Mg | 2655 | mg/kg DS | Cr | 21 | mg/kg DS |
| Pb | 35 | mg/kg DS | Cu | 82 | mg/kg DS |

### Recycling options in current research

Many different application areas are in focus for recycling of the sludge. The spread among the applications can be compiled like this:

- 5 water treatment
- 10 energy
- 10 products
- 2 chemical products

- 3 building/construction materials
- 2 land application/soil

A number of treatment methods and application areas are presented In Table 2.

### Environmental Limit values relevant to sludge use

Pulp and paper sludge cannot be awarded the European Union Community Ecolabel for soil improvers, because of the type of industry from which the sludge comes (2006, para. 1.2).

If regarded as compost or digestate from bio-waste, and assuming that the pathogen content does not exceed the limits, the metal content of the sludge would allow certification according to SPCR 152/120 published by SP Technical Research Institute of Sweden (SP) (2014, p. 13), (2015, p. 14).

The SPCR 148 standard for soil production from SP prescribes some limits for the metal content of the raw material used in soil production process (2006 Appendix 2, 3, 4, 5). The sludge does meet these restrictions and can therefore be used for soil production purposes. However, it does not meet the restrictions for the finished soil product due to the cadmium content. The sulphur content would also be too high if it occurred as sulphide; the sulphide level must not exceed 20 mg/kg DS for the finished product. Easily soluble phosphor, potassium and magnesium do meet both minimum and maximum limits.

If for any reason water application in lakes or streams was an option, comparison with the prescribed metal limits in SPCR 155 for liming products for acid lakes and wetlands published by SP would be relevant (2011 Appendix 2). The comparison reveals that the metals cobalt, chromium, copper, mercury, lead and zinc exceed the limits and therefore the sludge should not be used in lakes, streams or wetlands without prior metal removal.

Ash can be spread in forest land for its nutrient content. The Swedish forest agency has published limit values for metal content in ash and minimum limits for macro-nutrients (Emilsson, 2012). The content of macro-nutrients in ash from bio sludge is rather low – only Mg and P exceed their minimum limits. Data on the content of heavy metals in the ash is not analysed. But assuming that all the metals in the sludge end up in the ash and the ash content is 27% DS, the metal content would still be far below the limits. Therefore the ash from bio sludge would be accepted for forest application even though the nutrient content is low.

The certification standards applied are showing that the direct application of the sludge as it is, is approved in some cases but not by all. It is likely that these limit values can be decreased in coming years and therefore both direct application of the sludge as it is or using it as finished compost are only short term solutions. Most of the recycling methods have to handle the metal content in either a liquid fraction or a solid fraction. But if the metals are a problem that can be solved these alternatives can work. Production of glass and brick together with incineration and use as liming agent at landfills are less sensitive for the content of metals but utilizes the resource to a lesser extent.

The metals exceeding their limit values are mentioned in Table 3 together with their corresponding standards.

### Technology Readiness Level (TRL)

The results from the TRL are presented as a numeric value between 1 and 9. Levels 1–2 are ideas that exist only on paper. Levels 3–5 represent experiments in a laboratory. Level 6 means that the method has been tested at a pilot scale. Levels 7–9 correspond to an operational treatment at full scale that uses synthetic or the actual waste in a limited or full range. The configuration of the facility used is similar or identical to a commercial plant.

All of the application areas are present both in the beginning and the end of the table. Therefore it is difficult to see any trends. But energy applications are numerous and a large share of them are found to be relative mature. The results of the TRL assessment are found in Table 3.

### Circular economy

The answers from the company representatives do deviate from each other for each of the technologies. A precautious approach is used and the degree of circularity must not be overestimated. Therefore the average value and the standard deviation are used to calculate the lower statistical limit for degree of circularity. This calculated value is then used for selecting the top six methods with the highest degree of circularity.

There are not a single application area that dominate the more circular solutions. The answers show that several types of recycling methods can be perceived as circular. The results of the circular economy assessment is found in table 3.

### Technology assessment

If the focus is on mature solutions at level 5 or above, providing long-term solutions and utilisation of the sludge as a resource, the combined output from the certification standard assessment and the TRL is as follows:

- Production of SCP from hydrolysed fibre sludge (food)
- Gasification of sludge (energy)
- Thermo-alkali hydrolysis of sludge and use of the solid fraction for production of second-grade cardboard and the liquid fraction for anaerobic digestion (material and energy)
- Production of hydrogen by supercritical water gasification (energy)
- Production of lead adsorbent by hydrothermal carbonisation (operational with other waste) (water treatment)

The assessment of the degree of circularity reveals that the representatives do not classify the most mature methods as circular, except for the production of SCP, which is regarded as the most circular recycling method of the ones listed above. The production of lead adsorbent by HTC for water treatment is not regarded as circular, but production of active char by microwave-assisted pyrolysis for the same purpose is regarded as one of the top six candidates.

## 4 Discussion

Bio sludge has certain properties that are possible to exploit. The carbon content is very high, about 50% DS. Production of carbon-rich products could be a possible solution. This opens the door for active char applications. The protein content is also very high, so processing into protein-rich products is another possible path of recycling.

The SCP and HTC process is regarded as circular, as stated in the previous section, and the inherent properties of the sludge support these types of solutions. But in order for a choice between them to be possible, they should be compared to a relevant baseline alternative.

Incineration is a common solution today; volume reduction is high and the ash is available for extraction of useful substrates. Incineration with improved dewatering could be an alternative to a complete change in sludge use. Therefore incineration combined with efficient dewatering should be included in the LCA study.

# 5 CONCLUSION

The content of metals in the sludge exceed some of the current limit values and could in a greater extent exceed the future limit values if they will be lower than today. Therefore direct application of the sludge can only be a short term solution.

Most treatment methods produce either a liquid or solid residue and the metals could be concentrated in any of these, so the metals in the residue must be assessed regardless of which technology is used. To maximize the usefulness of the sludge it is essential to assume that the problem with the metals can be solved.

Production of bricks and glass stabilizes the metals but the resources are then locked in a matrix which make them to a lesser extent available for use.

Production of SCP and a lead adsorber are two alternatives that are regarded as both circular and relatively mature. These two should be assessed according to the LCA method, together with incineration combined with improved dewatering.

*Table 2 Technologies and application areas*

| No. | Technology | Application area | No. | Technology | Application area |
|---|---|---|---|---|---|
| 1 | Production of glass by vitrification[1] | Building materials | 2 | Microwave-assisted pyrolysis for active char production [2] | Water treatment |
| 3 | Heat production by incineration of bio sludge in a pulp mill recovery boiler[3] | Energy | 4 | Production of glucose by simultaneous saccharification and fermentation (SSF) using A. cellulolyticus [4] | Energy (Ethanol) |
| 5 | Use as liming agent at landfills[5] | Soil | 6 | Production of PHA (plastics) by fermentation of activated sludge [6] | Construction materials |

[1] (Blurton, 2006, p. 52)
[2] (Namazi et al., 2015)
[3] (Harila and Kivilinna, 1999, p. 195)
[4] (Prasetyo et al., 2010, pp. 1907, 1912)
[5] (Prasetyo et al., 2010)
[6] (Bengtsson et al., 2008, p. 509)

| | | | | | |
|---|---|---|---|---|---|
| 7 | Production of Pb(II) adsorbent by hydrothermal carbonisation[7][8] | Water treatment | 8 | Pyrolysis for production of magnetic char for adsorbent of pentachlorophenol [9] | Water treatment |
| 9 | Heat production by incineration of pulp mill waste water sludge in a circulating fluidised bed combustor[10] | Energy | 10 | Stabilisation of Zn and Pb in contaminated soils by addition of bio/fibre sludge [11] | Soil remediation |
| 11 | Thermo-alkali hydrolysis of sludge. After hydrolysation, the solid content was used for second-grade cardboard production and the liquid fraction for biogas production by UASB[12] | Combined material and energy | 12 | Biogas production with hydrothermal pre-treatment [13] | Energy |
| 13 | Production of hydrogen and methane by supercritical water gasification of bio sludge organic content [14] | Energy | 14 | Production of phenols, carboxylic acids, aldehydes, esters, carbohydrates, etc. by high pressure direct liquefaction [15] | Chemicals |
| 15 | Gasification of sludge from a pulp mill for hydrogen production[16] | Energy | 16 | Filamentous fungi for volume reduction combined with: a) production of fungal by-products like protein-rich animal fodder and/or b) degradation of phenol, dyes and PAH [17][18] | Biocontrol agent, biofertilisers, pharmaceutical, agricultural, industrial and environmental microbiology |

[7] (Alatalo et al., 2013)
[8] (Öhman and Fougner, 2014, p. 9)
[9] (Devi and Saroha, 2014)
[10] (Mahmoudi et al., 2010, pp. 1393, 1407)
[11] (Battaglia et al., 2007)
[12] (Kaluža et al., 2014, p. 137)
[13] (Wood et al., 2009, pp. 5729–5730)
[14] (Rönnlund et al., 2011, pp. 2152, 2162)
[15] (Zhang et al., 2011, p. 2142)
[16] (Cordiner et al., 2012, pp. 537, 541)
[17] (More et al., 2010, pp. 7695–7698)
[18] (Sankaran et al., 2010)

| | | | | | |
|---|---|---|---|---|---|
| 17 | Production of single cell protein (SCP) from hydrolysed fibre sludge [19] | Food | 18 | Production of bioflocculant by treatment with hydrochloric acid [20] | Water treatment |
| 19 | Sludge as replacement of clay for brick production [21] | Building materials | 20 | Mesophilic digestion of WAS pre-treated by microwaves at 125 °C [22] | Energy |
| 21 | Improvement of silty soil CBR and UCS by addition of sludge [23] | Land application | 22 | Anaerobic treatment of bio sludge and recycling of digestate as a source of nutrient in the activated sludge process while producing methane, reducing sludge volume and improving dewaterability [24] | Energy and water treatment |
| 23 | Biodrying by controlled composting with increased ventilation and thereafter incineration [25] | Energy | | | |

*Table 3 Technology assessment*

| No. | Problematic elements (corresponding standard) | Resulting TRL | Circular Economy | Comment |
|---|---|---|---|---|
| 1 | | 9 | 1.90 | Operational in Wisconsin, USA. |
| 3 | | 9 | 0.95 | Actual waste |
| 5 | | 9 | 0.78 | Operational in UK |

[19] (Backlund and Nordström, 2014, pp. 7, 43)
[20] (Zhang et al., 2013)
[21] (Wolff et al., 2015, pp. 282, 288)
[22] (Mehdizadeh et al., 2012, p. 176)
[23] (Güllü and Girisken, 2013)
[24] (Meyer and Edwards, 2014, pp. 327, 328)
[25] (Huiliñir and Villegas, 2014, p. 207)

| | | | | |
|---|---|---|---|---|
| 7 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) Cd, S. (SPCR148) | 8 - 9 | 1.11 | Laboratory tests with actual waste/Operational with other biomass |
| 9 | | 8 - 9 | 0.74 | Actual waste |
| 11 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) | 6 | 1.58 | Actual waste |
| 13 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) Cd, S. (SPCR148) | 6 | 1.22 | Actual waste |
| 15 | Cd, S. (SPCR148) | 6 | 1.05 | Actual waste |
| 17 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) Cd, S. (SPCR148) | 5 | 3.11 | |
| 19 | | 3 - 4 | 3.11 | Actual waste |
| 2 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) | 3 - 4 | 2.11 | Actual waste |
| 4 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) Cd, S. (SPCR148) | 3 - 4 | 2.11 | Actual waste |
| 6 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) Cd, S. (SPCR148) | 3 - 4 | 2.03 | Actual waste |
| 8 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) | 3 - 4 | 1.91 | Actual waste and simulated and actual contaminated effluent |
| 10 | Cd, S. (SPCR148) | 3 - 4 | 1.82 | |
| 12 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) Cd, S. (SPCR148) | 3 - 4 | 1.63 | Actual waste |
| 14 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) Cd, S. (SPCR148) | 3 - 4 | 1.60 | Actual waste |
| 16 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) Cd, S. (SPCR148) | 3 - 4 | 1.45 | Initial tests in shake flasks, no pre-treatment, choice of fungus type is critical |
| 18 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) Cd, S. (SPCR148) | 3 - 4 | 1.45 | Actual waste |

| | | | | |
|---|---|---|---|---|
| 20 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) Cd, S. (SPCR148) | 3 - 4 | 1.20 | Actual waste |
| 21 | Cd, S. (SPCR148) | 3 - 4 | 1.11 | |
| 23 | | 3 - 4 | 1.03 | Actual waste |
| 22 | Co, Cr, Cu, Hg, Pb, Zn. (SPCR155) Cd, S. (SPCR148) | | 2.45 | Review article |

# 6 References


Alatalo, S.-M., Repo, E., Mäkilä, E., Salonen, J., Vakkilainen, E., Sillanpää, M., 2013. Adsorption behavior of hydrothermally treated municipal sludge & pulp and paper industry sludge. Bioresour. Technol. 147, 71–76. doi:10.1016/j.biortech.2013.08.034

Backlund, B., Nordström, M., 2014. Nya produkter från skogsråvara En översikt av läget 2014 (Inventia No. 577). Stockholm.

Battaglia, A., Calace, N., Nardi, E., Petronio, B.M., Pietroletti, M., 2007. Reduction of Pb and Zn bioavailable forms in metal polluted soils due to paper mill sludge addition: Effects on Pb and Zn transferability to barley. Bioresour. Technol. 98, 2993–2999. doi:10.1016/j.biortech.2006.10.007

Cordiner, S., De Simone, G., Mulone, V., 2012. Experimental–numerical design of a biomass bubbling fluidized bed gasifier for paper sludge energy recovery. Appl. Energy, Energy Solutions for a Sustainable World - Proceedings of the Third International Conference on Applied Energy, May 16-18, 2011 - Perugia, Italy 97, 532–542. doi:10.1016/j.apenergy.2011.11.024

Devi, P., Saroha, A.K., 2014. Risk analysis of pyrolyzed biochar made from paper mill effluent treatment plant sludge for bioavailability and eco-toxicity of heavy metals. Bioresour. Technol. 162, 308–315. doi:10.1016/j.biortech.2014.03.093

Emilsson, S., 2012. Från skogsbränsleuttag till askåterföring.

Förordning (1998:944) om förbud m.m. i vissa fall i samband med hantering, införsel och utförsel av kemiska produkter, 1998. , SFS 1998.

Güllü, H., Girisken, S., 2013. Performance of fine-grained soil treated with industrial wastewater sludge. Environ. Earth Sci. 70, 777–788. doi:10.1007/s12665-012-2167-0

Gyllenhammar, M., Herstad Svärd, S., Kjörk, A., Larsson, S., Wennberg, O., Åmand, L.-E., Eskilsson, D., 2003. Branschprogram; Slam från skogsindustrin fas II [Sludge in the pulp and paper industry in Sweden, part II ] (Research results No. 840). Värmeforsk, Stockholm.

Henriksson, G., Palm, O., Davidsson, K., 2012. Right sludge to the right place (No. 41). Waste Refinery, Borås.

Huiliñir, C., Villegas, M., 2014. Biodrying of pulp and paper secondary sludge: Kinetics of volatile solids biodegradation. Bioresour. Technol. 157, 206–213. doi:10.1016/j.biortech.2014.01.109

Kaluža, L., Šuštaršič, M., Rutar, V., Zupančič, G.D., 2014. The re-use of Waste-Activated Sludge as part of a “zero-sludge” strategy for wastewater treatments in the pulp and paper industry. Bioresour. Technol. 151, 137–143. doi:10.1016/j.biortech.2013.10.041

Mahmoudi, S., Baeyens, J., Seville, J.P.K., 2010. NOx formation and selective non-catalytic reduction (SNCR) in a fluidized bed combustor of biomass. Biomass Bioenergy 34, 1393–1409. doi:10.1016/j.biombioe.2010.04.013

Mehdizadeh, S.N., Eskicioglu, C., Milani, A.S., Saha, M., 2012. Empirical modeling of the effects of emerging pretreatment methods on anaerobic digestion of pulp mill biosolids. Biochem. Eng. J. 68, 167–177. doi:10.1016/j.bej.2012.07.016

Meyer, T., Edwards, E.A., 2014. Anaerobic digestion of pulp and paper mill wastewater and sludge. Water Res. 65, 321–349. doi:10.1016/j.watres.2014.07.022

More, T.T., Yan, S., Tyagi, R.D., Surampalli, R.Y., 2010. Potential use of filamentous fungi for wastewater sludge treatment. Bioresour. Technol. 101, 7691–7700. doi:10.1016/j.biortech.2010.05.033

Norgren, R., 2012. Datablad Bioslam SS [Datasheet Biosludge SS].

Oden, P., 2012. Datablad Bioslam SO [Datasheet Biosludge SO].

Öhman, F., Fougner, K., 2014. Teknisk förstudie – Biokol från bioslam [Conceptual Study – Bio-coal from biological sludge ] (Research results No. 1252). Värmeforsk, Stockholm.

Rönnlund, I., Myréen, L., Lundqvist, K., Ahlbeck, J., Westerlund, T., 2011. Waste to energy by industrially integrated supercritical water gasification – Effects of alkali salts in residual by-products from the pulp and paper industry. Energy, 5th Dubrovnik Conference on Sustainable Development of Energy, Water & Environment Systems 36, 2151–2163. doi:10.1016/j.energy.2010.03.027

Sankaran, S., Khanal, S.K., Jasti, N., Jin, B., Pometto, A.L., Van Leeuwen, J.H., 2010. Use of Filamentous Fungi for Wastewater Treatment and Production of High Value Fungal Byproducts: A Review. Crit. Rev. Environ. Sci. Technol. 40, 400–449. doi:10.1080/10643380802278943

Sivard, Å., Ericsson, T., Krogerus, M., Stemme, S., 2013. Nuvärdesmaterial kring bioslam [Current situation for biosludge] (Project report). ÅF Industry AB, Stockholm.

SP Technical Research Institute of Sweden, 2015. Certifieringsregler för biogödsel SPCR 120 [Certification rules for digestate from biowaste].

SP Technical Research Institute of Sweden, 2014. Certifieringsregler för kompost - SPCR 152 [Certification rules for compost SPCR 152].

SP Technical Research Institute of Sweden, 2011. SPCR 155 sjökalk och våtmarkskalk [Certification of liming products for acid lakes and wetlands by P-marking ].

SP Technical Research Institute of Sweden, 2006. Certifieringsregler för P-märkning av anläggningsjordar SPCR 148.

Technology Readiness Assessment Guide (Guide No. DOE G 413.3-4A), 2011. . U.S. Department of Energy, Washinton.

The circular model - an overview [WWW Document], 2013. . Ellen MacArthur Found. URL http://www.ellenmacarthurfoundation.org/circular-economy/circular-economy/the-circular-model-an-overview (accessed 9.1.15).

The Commission of the European Communities, 2006. COMMISSION DECISION of 3 November 2006 establishing revised ecological criteria and the related assessment and verification requirements for the award of the Community eco-label to soil improvers.

The TRL Scale as a Research & Innovation Policy Tool, EARTO Recommendations (Opinion), 2014. . EARTO - European association of research and technology organisations.

Wolff, E., Schwabe, W.K., Conceição, S.V., 2015. Utilization of water treatment plant sludge in structural ceramics. J. Clean. Prod., Integrating Cleaner Production into Sustainability Strategies 96, 282–289. doi:10.1016/j.jclepro.2014.06.018

Wood, N., Tran, H., Master, E., 2009. Pretreatment of pulp mill secondary sludge for high-rate anaerobic conversion to biogas. Bioresour. Technol. 100, 5729–5735. doi:10.1016/j.biortech.2009.06.062

Zhang, L., Champagne, P., (Charles) Xu, C., 2011. Bio-crude production from secondary pulp/paper-mill sludge and waste newspaper via co-liquefaction in hot-compressed water. Energy, 5th Dubrovnik Conference on Sustainable Development of Energy, Water & Environment Systems 36, 2142–2150. doi:10.1016/j.energy.2010.05.029

Zhang, X., Sun, J., Liu, X., Zhou, J., 2013. Production and flocculating performance of sludge bioflocculant from biological sludge. Bioresour. Technol. 146, 51–56. doi:10.1016/j.biortech.2013.07.036