Novel biotechnical cascade concept to upgrade pulp and paper residues to hydrogen gas and polyhydroxyalkanoate (PHA)

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Introduction:
Pulp and paper mills use large volumes of water that has to be treated before being discharged. In most cases, the effluent is treated with aerobic biological processes using electricity for aeration, and added nutrients. The bio-sludge has low energy value and has to be disposed of. Here, we propose that effluent instead can be used as a feedstock for valuable products.

Valuable products from pulp and paper wastewater treatment
Some of the bacteria in the bio-sludge has the ability to accumulate polyhydroxyalkanoates (PHAs) as energy reserve. The PHAs can then be extracted from the biomass. PHAs can be found in the global marketplace as biodegradable plastics with a number of applications. Today produced in monocultures. For an efficient PHA accumulation, volatile fatty acids (VFAs) are needed as the feedstock substrate. Process streams from pulp and paper mills, rich in pentose sugars, can be fermented by the thermophilic bacteria *Caldicellulosiruptor*, providing acetic acid and hydrogen gas. The acetic acid can then be used as substrate for PHA accumulation. The hydrogen is both an energy carrier and a valuable product as reducing agent in the chemical industry.

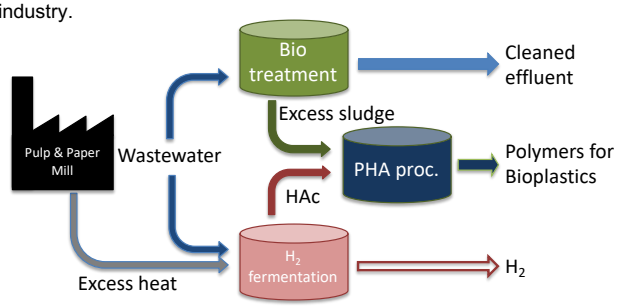

Figure 1: Principe for cascade concept were the effluent is used for new products while it is being cleaned.

Method:
During this project, University, Research Institutes, consultants and industry worked together to evaluate the novel biotechnical cascade concept. In a case study conducted with data from four pulp and paper mills in Sweden, the theoretical production volume of hydrogen gas and PHA were estimated. Possibilities and risks were discussed with representatives from the forest industry. The results were evaluated with a simplified LCA and the values of the new products were estimated.

Results:
The results indicate that it is possible to produce considerable quantities of PHA and hydrogen gas from the forest industry wastewater streams. For three of the four mills analysed, the estimated yields were between 800 and 2000 tons per year of PHA and between 50 and 200 tons per year of hydrogen gas. At the same time, the TOC load to the wastewater treatment and the bio-sludge production decreases. And less energy are needed for the aeration and sludge handling.

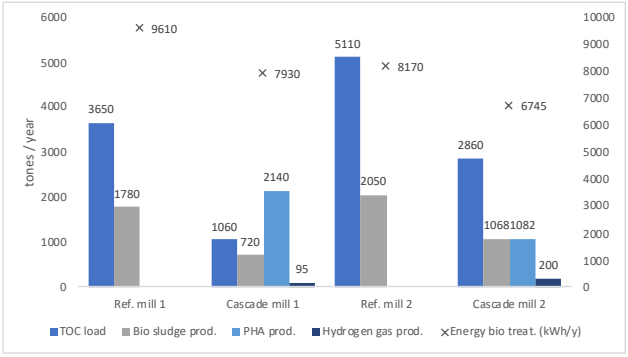

Figure 2: Consequences in the bio-treatment for two mill cases. Reference and with the cascade concept.

A simplified environmental life-cycle analysis confirmed the environmental benefits – with regard to reduction in greenhouse gas emissions - of recovering PHA and hydrogen gas from the wastewater stream.

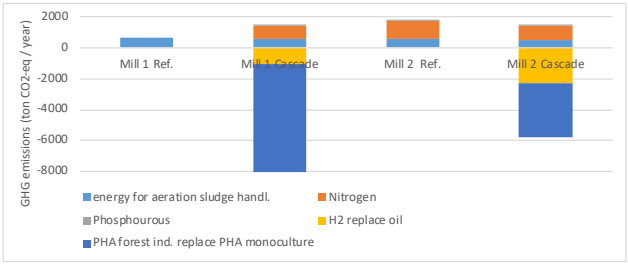

Figure 3: Results from LCA. GHG emissions for two mill cases, reference and with the cascade concept.

The market value of these products, on date, is between 40-100 million SEK per year, for each of the mills. There is thus a clear synergy with the potential to yield economic and environmental benefits, which needs to be harnessed in the near future.

Discussion:
With this cascade process, new businesses can evolve, utilising the waste stream from existing businesses in the forest industry. The latter thereby are able to offload some of their 'burden' – in this case the need to treat the wastewater before discharge – and the former can, while contributing to the circular bio-economy, establish themselves in the global marketplace, by virtue of new sustainable products suitable for the 21st century. Bio-economic productivity of regions can thus be enhanced over time.

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