
# Power-to-Protein: next step towards consumable single cell proteins from waste water and renewable hydrogen

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**Abstract:**

In the Power-to-Protein concept lithotrophic hydrogen oxidizing bacteria reassemble carbon dioxide and ammonium-nitrogen from sewage treatment to single cell protein (SCP) while using hydrogen as energy source. In this way, the inefficient anthropogenic nitrogen cycle can be short-circuited. In this study the concept was scaled up by designing and building a pilot plant with a reactor volume of 500 litres. The concept was demonstrated at two sewage treatment plants (STPs) in The Netherlands. Parallel to the Power-to-Protein pilot an ammonia recovery pilot was tested for removal efficiency of pathogens while producing ammonia sulphate from reject water of the sludge digestion. Special attention was given to the quality aspects of the SCP that was produced especially with regard to crude protein content, amino acid sequence and in vitro digestibility. A Life Cycle Analysis was performed to compare the production of SCP with traditional protein sources.
**Keywords**: Resource recovery; single cell protein; ammonia reuse

## Introduction

The concept “power-to-protein” (PtP-concept) was first introduced by Ghent University, and is about the production of high-value protein through biosynthesis on site of sewage treatment plants using hydrogen, oxygen and carbon dioxide (see figure 1.1). Nitrogen, as ammonia, is required as main building block of the protein, and can be retrieved directly from the waste water matrix, e.g. from the liquid fraction of anaerobic digestion (reject water). The biosynthesis of single cell protein (SCP) is performed by a mixed culture enriched in hydrogen-oxidizing bacteria (HOB microbiome) (Matassa et al., 2015a). The concept offers good opportunities to up-cycle used nitrogen in a short track, thus preventing energy consuming processes for fertilizer production at the beginning of the nitrogen-cycle as well as ammonia removal in STPs at the end of the cycle (Matassa et al., 2015b).

The technical feasibility of the concept was demonstrated by Avecom in their laboratory in Gent by producing autotrophic hydrogen-oxidizing bacteria at 5 L scale. The produced microbial biomass was harvested and the amino acids profile of the produced edible microbial protein was analysed, indicating a high quality product that could replace conventional feed sources such as fishmeal or soybean meal.

For the economic feasibility of the concept a desk study was performed using actual data from the centrally located biological sludge digestion system of the two STPs in the city of Amsterdam. The results, showing a good economic potential, were presented at the IWA 2016 World Water Congress & Exhibition in Brisbane (Oesterholt, 2016).

## Material and Methods

The work was continued in recent years by designing and building a pilot plant reactor with an intended production capacity of about 1 kg SCP per day. As hydrogen is the energy source of the HOB microbiome, special attention had to be paid to the design and construction of the pilot plant so that operational safety can be assured. The pilot plant was used to demonstrate the production of SCP and to monitor the production process at two STPs in The Netherlands.

To feed the power-to-protein pilot with recovered ammonia an existing pilot scale ammonia recovery system was used. This pilot plant (NAR-pilot, Nijhuis Water Technology) is based on air stripping at elevated temperatures and pH followed by absorption of the stripped ammonia in a sulphuric acid solution. On both locations, the reject water of the sludge digestion plants was used as source for the ammonia recovery step. This step is significant for the overall economics of the PtP-concept. The different steps within the NAR-pilot were closely monitored, particularly in terms of pathogens transfer from the reject water to the final ammonium sulphate solution produced. For this purpose challenge tests were performed with three indicator microorganisms to prove sufficient virus, bacteria and protozoa removal.

The biomass produced in the PtP-pilot was analysed for protein content, amino acids composition and in-vitro digestibility. The environmental impact of SCP was evaluated by performing a Life Cycle Analysis using SimaPro software and the EcoInvent 3.0 database.

## Results and conclusions

Ammonia recovery using air stripping at elevated temperatures and pH turns out to be technically and economically feasible. The total costs of € 2.18 per kgN can be further reduced to € 1.54 per kgN when waste heat is available on location. Challenge test results show high removal efficiencies for indicator organisms (see table 1.1.) indicating that transfer of faecal pathogens from the reject water to the recovered ammonia sulphate is very unlikely.

The quality of the produced SCP in the pilot reactor is compared to the product from the lab scale test. The crude protein content is lower (49 % and 75 % respectively) and so are the concentrations of essential amino acids. The in-vitro digestibility of the produced SCP is comparable to that of fishmeal.

LCA results indicate that – due to the amount of electricity necessary for the hydrogen (and oxygen) production - the source of electricity is the determining factor in the case of environmental impact of SCP. So the “greener” the power source the lower the impact. In figure 1.2 a comparison is made between SCP and conventional protein sources per kg crude product for “off shore wind’ as a common power source in the future. With the interpretation of these data it is important to understand that the crude protein content of SCP is substantial higher than that of meat.

Pilot results in general indicate insufficient hydrogen transfer efficiency in the pilot reactor resulting in direct loss of hydrogen and a relatively low specific SCP production capacity. Indirectly the low gas transfer of gasses in the reactor has had a negative influence on SCP-quality as well. So optimisation of the reactor concept in general and the hydrogen transfer in particular are crucial for the continuation of the PtP-concept.

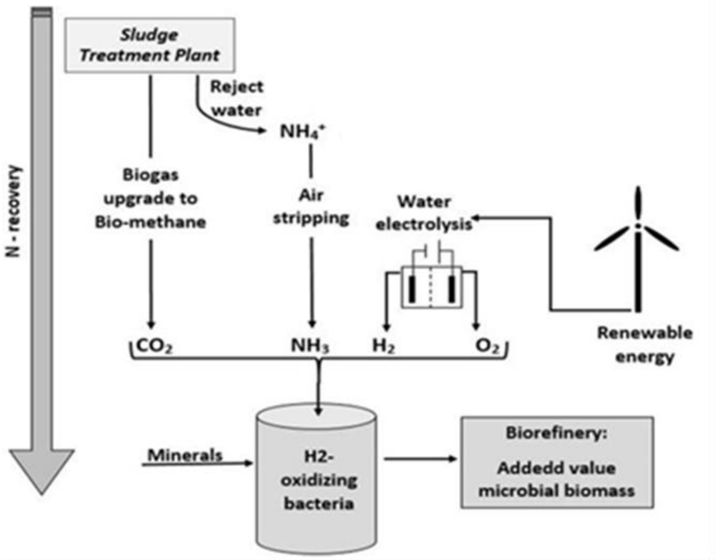


**Figure 1.1** Process scheme power-to-protein concept

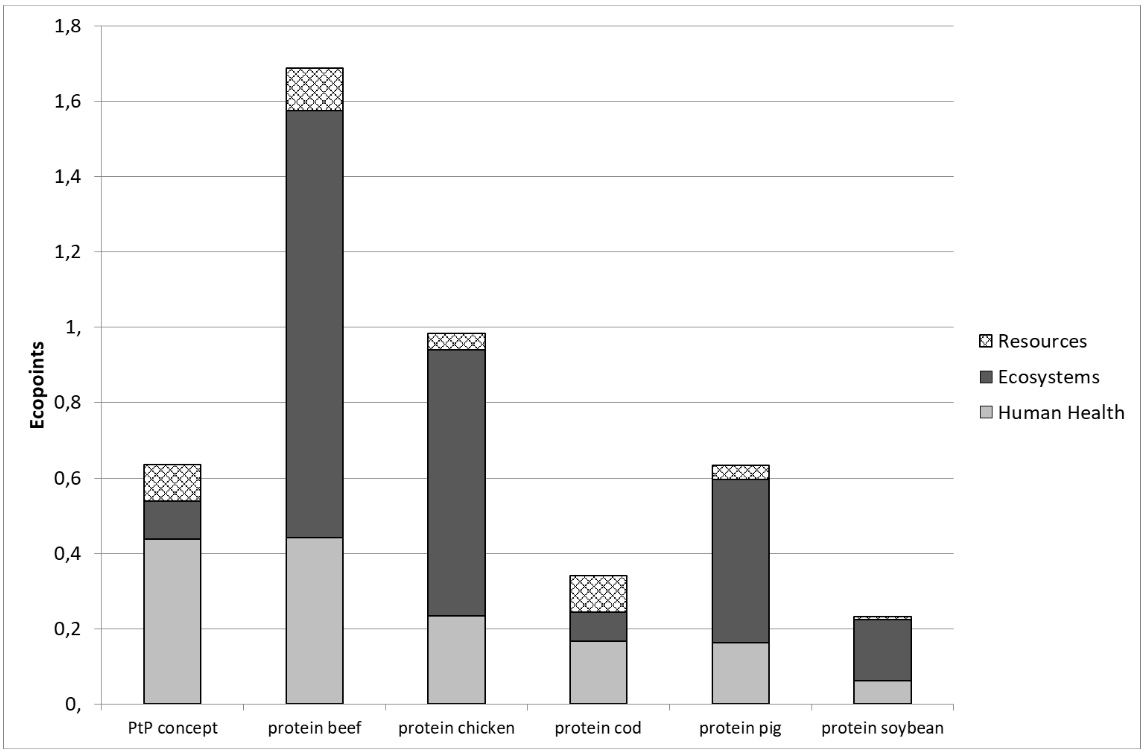


**Figure 1.2** Environmental impact on three midpoint of different protein sources per kg crude product

**Table 1.1** Results of two challenge tests with indicator organisms in the ammonia recovery pilot

| | T | Salmonella senftenberg | SSRC | Coliphages phiX174 |
|---|---|---|---|---|
| | °C | MPN/l | CFU/l | PFU/l |
| *Test 1 June 30 2017* | | | | |
| Influent + inoculate | 24,2 | > 3,7 *$10^4$ | 4,2 * $10^7$ | 1,9*$10^7$ |
| $(NH_4)SO_4$ from scrubber | 60,1 | < 0,6 | 5,8 * $10^3$ | < 100 |
| **Overall log removal** | | **> 6,4** | **5,5** | **> 6,9** |
| | | | | |
| *Test 2 August 7 2017* | | | | |
| Influent + inoculate | 24,2 | 7,8 *$10^7$ | 8,4 * $10^6$ | 7,7*$10^6$ |
| $(NH_4)SO_4$ from scrubber | 60,1 | < 0,6 | 1,7 * $10^3$ | < 100 |
| **Overall log removal** | | **> 10,1** | **5,7** | **> 6,9** |

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