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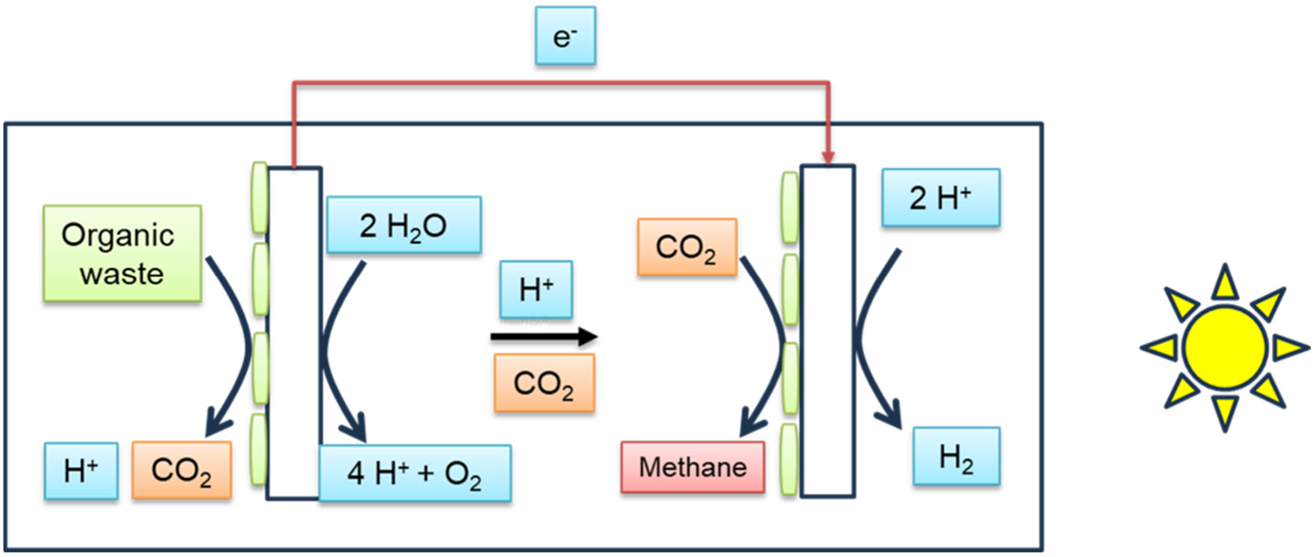
Interim report from 2026

LightMe

Solar Bio-Electro-Methanization



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Summary

This project will facilitate the development of bioelectric methanisation through direct light irradiation. The work is based on a new technology known as solar microbial electrolysis, or synthesis. This will result in the production of biomethane with higher yields than in conventional biogas production. This is the first time that the integration of solar light into bioelectric systems is investigated in the context of biogas production. The extent to which the anode and cathode function in such systems when light is used as an additional energy source to complement microbial energy will be demonstrated. The work includes using microbial cultures to verify model processes and obtain data for process analysis. These methods will be applied in the final stage to solar methanisation of sewage sludge under real conditions. To assess the scope of the task more precisely, literature research is conducted that encompasses the specifics of the anode and cathode processes. Experiments will be performed in a dual-chambered microbial electrolysis/electrosynthesis cell.

Zusammenfassung

In diesem Projekt wird die bioelektrische Methanisierung durch direkte Lichtbestrahlung untersucht. Die Arbeit basiert auf der sogenannten solaren mikrobiellen Elektrolyse bzw. Synthese. Dadurch wird Biomethan mit höheren Erträgen als bei der herkömmlichen Biogasproduktion produziert. Es ist das erste Mal, dass die Integration von Solarlicht in bioelektrische Systeme im Kontext der Biogasproduktion untersucht wird. Demonstriert wird, inwieweit Anode und Kathode in solchen Systemen funktionieren, wenn Licht als zusätzliche Energiequelle zur Ergänzung der mikrobiellen Energie genutzt wird. Die Arbeit umfasst die Verwendung mikrobieller Kulturen zur Verifikation von Modellprozessen und zur Gewinnung von Daten für die Prozessanalyse. Diese Methoden werden in der Endphase zur solaren Methanisierung von Abwasserschlamm unter realen Bedingungen angewandt. Um den Umfang der Aufgabe präziser bewerten zu können, wird eine Literaturrecherche durchgeführt, die die Einzelheiten der Anoden- und Kathodenprozesse umfasst. Die Experimente werden in einer zweikammerigen mikrobiellen Elektrolyse-/Elektrosynthesezelle durchgeführt.

Résumé

Dans ce projet, la méthanisation bioélectrique par irradiation directe de la lumière est étudiée. Le travail repose sur la soi-disant électrolyse ou synthèse microbienne solaire. En conséquence, le biométhane est produit avec des rendements supérieurs à ceux de la production conventionnelle de biogaz. C'est la première fois que l'intégration de la lumière solaire dans les systèmes bioélectriques est étudiée dans le contexte de la production de biogaz. La mesure dans laquelle l'anode et la cathode fonctionnent dans de tels systèmes est démontrée lorsque la lumière est utilisée comme source d'énergie supplémentaire pour compléter l'énergie microbienne. Le travail comprend l'utilisation de cultures microbiennes pour vérifier les procédés modèles et obtenir des données destinées à l'analyse des procédés. Ces méthodes sont appliquées en phase finale pour la méthanisation solaire des boues d'eaux usées dans des conditions réelles. Afin de pouvoir évaluer plus précisément l'étendue de la tâche, une revue de la littérature est réalisée incluant les détails des processus d'anode et de cathode. Les expériences seront menées dans une cellule microbienne d'électrolyse/électrosynthèse à deux chambres.

1 Introduction

1.1 Context and motivation

The proposed project will develop the integration of light energy into the microbial electrolysis process for the methanisation of sewage sludge (Fig. 1). The integration of light fundamentally increases the energy density in the bioelectric reactor. To date, nothing is known about the stability of methanogenic bacteria in light-assisted bioelectric reactors. Therefore, the project will investigate how methanogenic bacteria, which convert organic compounds, hydrogen and CO_2 into methane, can form biofilms in a suitable system and to what extent their metabolism tolerates light. Depending on the results, the processes will be adjusted accordingly. Solar bioelectrocatalytic systems can be operated in various ways. Light irradiation on the cathode is an area of the planned investigations that has not yet been extensively researched. This promotes the growth of photobiological microbes of unknown species when untreated sewage sludge is used. Membranes can prevent this development. It is also not known whether the use of light-transmissive membranes has a negative effect on the anode and whether dark membranes can block the radiation. Furthermore, the reactors will be adapted to the requirements so that the new process can run efficiently. The process of solar microbial electrolysis for methanisation is being investigated first. It is assumed that additional hydrogen production will solve the stoichiometric problem of electromethanisation from sewage sludge. In addition, the influence of oxygen evolution during water electrolysis is being considered. The use of photocathodes is particularly crucial for the utilisation of this solar electrolysis reactor. These cathodes are made of semiconductors and can be operated with or without hydrogen catalysts. This makes it possible to investigate whether electrons and protons can be introduced directly into the metabolism of methanogenic bacteria, or whether the process must take place via in situ production of hydrogen due to the fixation of ruthenium catalysts on the semiconductor surface. Ultimately, the best electrode concepts will be combined. Sequential processes can also be developed, which require the use of two connected reactors that operate in tandem. For example, one purifies wastewater and the other methanises sewage sludge, both of which are powered by light.

1.2 Project objectives

Design and construction of the light-irradiated microbial electrolysis cell:

The electrolysis cells are made of glass so that they can be equipped with various components in a modular fashion. LED lamps with a solar light spectrum are built and used as the light source. These are built at HESSO Sitten. The light source is equipped with a controller that can automatically vary the light intensity and light-dark phases. The electrodes consist of either cut-to-size carbon foam (reticulated vitreous carbon, RVC) for anodes or cathodes made of silicon (Si) and titanium oxide (TiO_2), both of which are relatively stable semiconductors. Molybdenum sulphides (MoS_2 and MoS_x) and stabilised copper oxide (Cu_2O) are also being considered. Newer semiconductors that have not yet been tested in photo bioelectric systems such as copper indium gallium diselenide (CIGS) and tungsten diselenide (WSe_2). The latter planned to being used for the first time. We expect good stability and productivity from these. To enable good usage properties, the semiconductor surfaces are coated with titanium oxide and other layers to improve their efficiency and durability. Ruthenium is used as the outermost coating to enable hydrogen production what is planned to not use for real extracellular electron uptake In addition, the development of specific functional models is under investigation. In particular, the focus is on determining whether the electrodes can transfer electrons directly from the semiconductor's conduction band to the microbes. This can be done through direct hydrogen transfer or via prior hydrogen evolution, known as indirect hydrogen transfer.

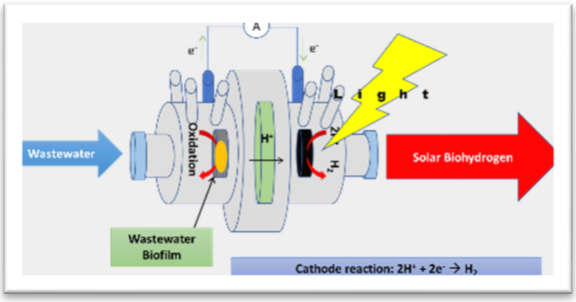

Figure 2: Top: Microbial electrolysis cell (MEC) working with activated sewage sludge producing hydrogen.

Light tolerance and the associated kinetics of various methanogenic bacteria:

The methanogenic bacteria *Methanobacterium palustre* and *Methanosarcina barkerii* are being studied to determine their function under the influence of light. To this end, model parameters are being formulated and used to systematically test the possible altered metabolic pathways and, if necessary, compare the results with other available methanogenic bacteria. In addition to pure microbial cultures, mixed cultures from the sewage sludge inoculum of the wastewater treatment plant in Sion are also being investigated for comparable use in the microbial electrolysis cell.

Process for sewage sludge methanisation under the influence of light:

The use of sewage sludge under light irradiation is examined in terms of its microbiological structure in the anodes and cathodes of the microbial electrolysis cell. The limitations of the process and the process variants are identified and their efficiency further optimized. In principle, microbial electrolysis can be carried out with or without membranes. With a clear separation into anode and cathode processes, operation with sewage sludge and wastewater is possible. In a shared process chamber with both electrodes, only methanisation is possible. This light process has not yet been researched, and the expected difficulties are algae formation in the cathode when sewage sludge is used. Furthermore, the photoelectrodes can become covered with deposits, reducing their function and durability. However, the processes can also be carried out separately and thus divided into sequential or parallel processes. It is being clarified whether sewage sludge solutions could be too dark and to what extent the light intensity needs to be modulated to compensate for any turbidity. Preliminary work has shown that sewage sludge suspensions usually become completely clear or transparent, which remains to be investigated here.

Cathode processes:

The cathode process (Eq. 3) serves to reduce the CO_2 content via methanogenic bacteria. The aim of this cathode process is to use silicon and other suitable stable semiconductor photoelectrodes. Two scenarios for their use are assumed. These are direct light-induced pseudo-hydrogen transfer and transfer with intermediately formed hydrogen from the same constellation. In the first case, the photoelectrode is coated with a layer that increases conductivity to the microbes, and in the second case, ruthenium oxide is applied. If necessary, the semiconductor electrodes are coated with a thin protective layer, such as a TiO_2 layer, to achieve direct hydrogen transfer and make the electrodes durable. If this is not successful, only a conductive back side can be in contact with the reaction solution, whereby it remains to be investigated whether both hydrogen transfer variants are possible there as well.

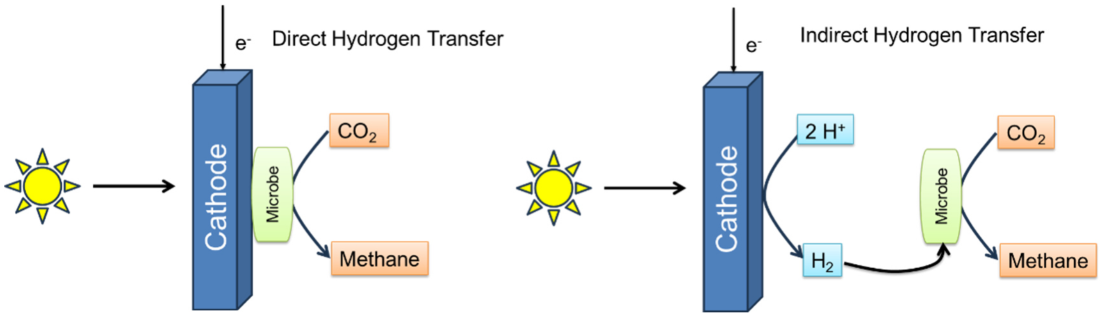

Figure 3: Left: Desired cathode process with direct electron and hydrogen transfer to the reducing microbe. Right: Expected side reaction that should be avoided. Here, indirect hydrogen transfer occurs, where H_2 is first formed and can also escape from the reactor (for stoichiometry, see Eqs. 3 and 4).