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Prediction of sunlight-driven CO_2 conversion: Producing methane from photovoltaics, and full system design for single-house application

F. Vieira [a, 1], B. Sarmento [a, 1], A.S. Reis-Machado [b, *], J. Facão [c], M.J. Carvalho [c], M.J. Mendes [a, **], E. Fortunato [a], R. Martins [a]

[a] i3N/CENIMAT, Faculty of Science and Technology, Department of Materials Science, Universidade NOVA de Lisboa and CEMOP/UNINOVA, Campus de Caparica, 2829-516 Caparica, Portugal

[b] LAQV, REQUIMTE, Departamento de Química, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Campus de Caparica, 2829-516 Caparica, Portugal

[c] LNEG, National Laboratory of Energy and Geology, Estrada do Paço do Lumiar, 22, 1649-038 Lisboa, Portugal

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A B S T R A C T

CO_2 capture and utilization (CCU) technologies are being immensely researched as means to close the anthropogenic carbon cycle. One approach known as artificial photosynthesis uses solar energy from photovoltaics (PV), carbon dioxide and water to generate hydrocarbon fuels, being methane (CH_4) a preferential target due to the already in place infrastructures for its storage, distribution and consumption. Here, a model is developed to simulate a direct (1-step) solar methane production approach, which is studied in two scenarios: first, we compare it against a more conventional 2-step methane production route, and second, we apply it to address the energetic needs of concept buildings with usual space and domestic hot water heating requirements. The analysed 2-step process consists in the PV-powered synthesis of an intermediate fuel – syngas – followed by its conversion to CH_4 via a Fischer–Tropsch (methanation) process. It was found that the 1-step route could be adequate to a domestic, small scale use, potentially providing energy for a single-family house, whilst the 2-step can be used in both small and large scale applications, from domestic to industrial uses. In terms of overall solar-to-CH_4 energy efficiency, the 2-step method reaches 13.26% against the 9.18% reached by the 1-step method. Next, the application of the direct solar methane technology is analysed for domestic buildings, in different European locations, equipped with a combination of solar thermal collectors (STCs) and PV panels, in which the heating needs that cannot be fulfilled by the STCs are satisfied by the combustion of methane synthesized by the PV-powered electrolyzers. Various combinations of situations for a whole year were studied and it was found that this auxiliary system can produce, per m^2 of PV area, in the worst case scenario 23.6 g/day (0.328 kWh/day) of methane in Stockholm, and in the best case scenario 47.4 g/day (0.658 kWh/day) in Lisbon.

1. Introduction

In the past centuries, the utilization of carbon-rich fossil fuels – coal, oil and natural gas – has allowed an unprecedented era of prosperity and advancement for human development, but also the increase of its concentration in the atmosphere from ~278 ppm, before the industrial revolution, to 403 ppm in 2016 [1–7]. The increase in CO_2 emissions has been shown to contribute to the increase in global temperature and climate change due to the greenhouse effect, posing a critical threat to the environment. Also, the present high dependence of fossil fuels for energy production worldwide constitutes a serious concern, since fossil fuels reserves are finite, and are becoming depleted. A novel approach that is attracting a significant amount of interest is carbon capture and utilization (CCU), whereby captured CO_2 is converted into a

* Corresponding author.
** Corresponding author.
E-mail addresses: ams.machado@fct.unl.pt (A.S. Reis-Machado), mj.mendes@fct.unl.pt (M.J. Mendes).

[1] The first two authors contributed equally to this work.

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