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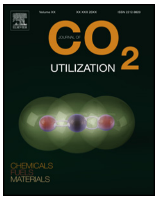

Techno-economic assessment of power-to-methane and power-to-syngas business models for sustainable carbon dioxide utilization in coal-to-liquid facilities

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ABSTRACT

The work reported in this paper aimed to evaluate and assess the technical and economic prospects of implementing a renewable-energy-based technology namely power-to-gas (PtG) for sustainable utilization of CO_2 emissions from syngas islands within coal-to-liquid facilities. Two possible PtG technology vectors (business models) namely power-to-methane (PtM) and power-to-syngas (PtS) were investigated. Three cases for each business model were developed namely PtM-Scenarios 1–3 and PtS-Scenarios 1–3 corresponding to CO_2 feed-in scales 10%, 20%, and 50% of the total CO_2 emission throughput, respectively. The mass flows generated for each case were used to develop a cost model, which evaluated and compared the economic merits of the various scenarios of the PtM and PtS value propositions based on an economic indicator vis-à-vis levelized cost of syngas production (LCOS). This study indicated that at present market conditions, only PtS-Scenarios 1–2 demonstrated cost competitiveness against the reference syngas plant. In addition, we concluded that PtM is not a viable proposition for sustainable CO_2 utilization in coal-to-liquid facilities at least for the near-to-medium term. However, a sensitivity analysis indicated that viability for PtM Scenarios 1–2 and all PtS business model scenarios is possible under future market conditions particularly when the CAPEX and OPEX relating to methanation and electrolyzers decrease, low electricity price, as well as when a CO_2 emission credit/tax scheme (>30 $/ton) is instigated for the reference syngas plant. Even so, it will not be possible to completely decarbonise a syngas plant within a coal-to-liquid facility using power-to-gas at competitive costs.

1. Introduction

The world today is fast-approaching an energy crisis defined by an ever-increasing gap between energy supply and demand [1]. At the same time, efforts being made towards correcting this disparity have resulted in increased carbon dioxide (CO_2) emissions to the atmosphere. Consequently, the central theme of realizing simultaneous energy and environmental security is one of the most important challenges of the 21st century. To address this combined challenge, a total shift in approach is required that disregards complete phase-out of fossils towards a reasonable concession that fossil fuels remain a significant energy resource for the foreseeable future. On the foregoing, advances in sustainable energy systems need to be founded on abundant yet carbon-intensive fossil fuels coupled to innovative green technologies such as carbon capture and utilisation (CCU). In this way, CO_2 can be turned from liability into opportunity.

An ideal prospect for implementation of CCU exists in coal-to-liquids (CTL) facilities that produce synthetic fuels in coal-abundant nations such as South Africa and China. In South Africa, for example, Sasol is operating the world's largest CTL facility producing 150,000 bpd of synthetic crude. Yet, this CTL facility is one of the planet's single largest point-source of CO_2 emissions, emitting 50 million tonnes of CO_2 annually [2,3]. Whilst CTL

Abbreviations: ASU, air separation unit; bpd, barrels per day; CAPEX, capital expenditure; CCU, carbon capture and utilization; CTL, coal-to-liquids; DME, dimethyl ether; FOB, free-on-board; FT, fischer-tropsch; HHV, higher heating value; IGCC, integrated gasification combined cycle; LCOS, levelized cost of syngas production; m.a.f., moisture and ash free; NG, natural gas; OPEX, operating expenditure; O&M, operating and maintenance; PtG, power-to-gas; PtH, power-to-hydrogen; PtM, power-to-methane; PtS, power-to-syngas; RWGS, reverse water gas shift; SOTA, state-of-the-art; SOEC, solid oxide electrolysis cells; tpd, tons per day; WGS, water gas shift.

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facilities have eased the energy security constraints on one hand, they remain incompatible with progressive climate policies of today. In fact, the possible implementation of stringent CO_2 mitigation policy instruments such as carbon tax threaten the viability of CTL so that industrial and political stakeholders are only willing to consider CTL if combined with CCU [4].

CCU is not an entirely new concept and has been actively pursued globally by research entities for decades using various pathways [5]. Until recently, the production of hydrogen has been a notable drawback to implementing CCU on a commercial basis. In this paper, however, we consider a forward-looking approach to CCU with renewable energy (solar or wind) integration in the context of a fundamentally new technology concept called "power-to-gas" (PtG) applied to a hypothetical syngas plant within a CTL facility. Power-to-gas involves converting excess renewable electricity into a chemical energy carrier including but not limited to hydrogen for long-term energy storage [6–16]. Basically, the excess electricity is used to produce "renewable hydrogen" via water electrolysis. The recent commercial breakthrough of renewable hydrogen production by way of water electrolyzer technologies has been an important enabler to warrant reconsideration of CCU. There are various power-to-X technological pathways in which renewable hydrogen can be used in combination with CCU to produce valuable chemicals such as methane, syngas, methanol to name a few. Specifically, Fig. 1 shows two PtG business models or value propositions that are evaluated in this paper namely power-to-methane (methanation) and power-to-syngas (RWGS).

The power-to-methane (PtM) value proposition is increasingly gaining popularity owing to the flexible uses of methane and its assured feed-in into the gas distribution system without stringent restrictions that otherwise limit direct power-to-hydrogen applications [10]. In a CTL facility, for example, methane can be used to fire gas turbines in a power-to-methane-to-power strategy as well as a co-feed to gasifiers or otherwise be sold on the market. On the other hand, power-to-syngas (PtS) can also be considered an innovative business model for a CTL facility in view of the additional syngas production capacity contribution via the reverse water gas shift (RWGS) or otherwise used as a building block for chemicals production such as methanol. The overall efficiency of these value propositions is however largely dependent on the purity of the carbon dioxide [17], with concentrated CO_2 sources being more cost-effective and therefore more favourable for CCU than lean sources. Indeed, syngas plants within CTL facilities produce high-purity CO_2 (>98%) and at high-throughput capacities to warrant for broader implementation of PtG towards large-scale commercialization.

In a comprehensive review, Gahleitner [10] presented an overview of the existing, planned and future PtG installations. Most of the installations consider renewable hydrogen production alone (power-to-hydrogen), whilst only a few demonstration scale projects have implemented PtG for CCU. For instance, ETOGAS GmbH (formerly SolarFuel GmbH, Germany) and ZSW (Center for Solar Energy and Hydrogen Research) have been operating a 250 kW_e methanation demonstration plant in Stuttgart (Germany) for delivering methane at a fueling station since 2012 [18]. In 2013, the first industry-scale and world's largest power-to-methane plant was realized by ETOGAS for Audi AG in Werlte, Germany. The 6 MW_e plant uses CO_2 from a waste-biogas plant to produce 1000 t of renewable methane into the existing natural gas network for distribution to the filling stations [19,20]. In 2012, Carbon Recycling International (CRI) started operating the George Olah Renewable Methanol Plant (CO_2-to-methanol) which uses geothermal electricity and CO_2 emissions from a near-by gas-to-liquids plant to produce 2 million litres of renewable methanol per annum [5,21]. Still, PtG strategies with CCU have not yet been implemented to decarbonise on a large scale as that forecasted for CTL facilities. In addition, the state-of-the-art (small-scale) PtG plants have been in operation for only a short time, and therefore lack operational experience. Almost without exception, the costs involved and economics remains widely unknown particularly for upscaling.

Few previous studies have reported techno-economic assessments for various PtG scenarios. Schiebahn et al. [22] compared three different PtG scenarios namely PtH for injection into natural gas infrastructure, PtM for injection into natural gas infrastructure, and PtH for the transport sector in Germany. The most viable case was found for the PtH for transport sector. De Saint Jean et al. [23]

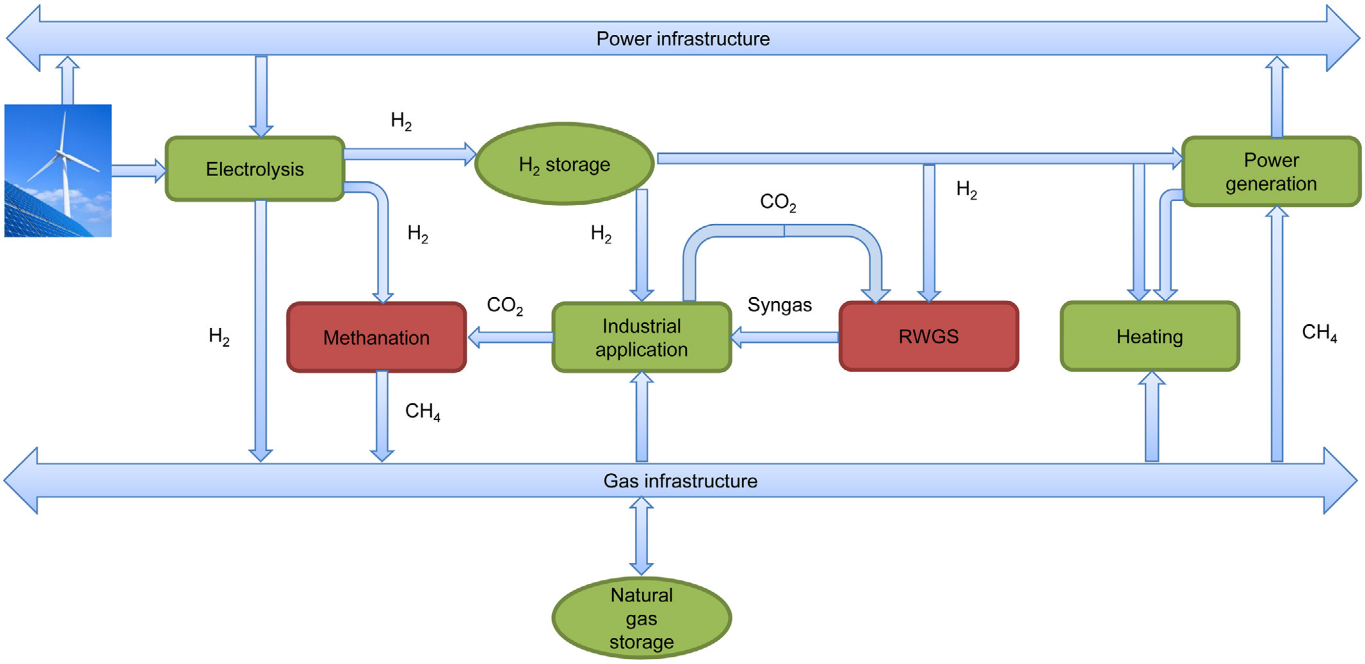

Fig. 1. Technological pathways for power-to-gas.