



Trends in CO₂ conversion and utilization: A review from process systems perspective



Ahmad Rafiee^a, Kaveh Rajab Khalilpour^{b,c,*}, Dia Milani^d, Mehdi Panahi^e

^a Cardiff School of Engineering, Cardiff University, Cardiff, CF24 3AA, UK

^b Faculty of Information Technology, Monash University, Melbourne, VIC, 3145, Australia

^c Energy Change Institute, Australian National University, Canberra, ACT, 2601, Australia

^d CSIRO Energy Centre, Mayfield West, NSW, 2304, Australia

^e Chemical Engineering Department, Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

ARTICLE INFO

Keywords:

CO₂ conversion
CO₂ valorization
Chemical and fuel synthesis
Climate change mitigation
Process systems engineering

ABSTRACT

Carbon capture and storage (CCS) community has been struggling over the past few decades to demonstrate the economic feasibility of CO₂ sequestration. Nevertheless, in practice, it has only proven feasible under conditions with a market for the recovered CO₂, such as in the beverage industry or enhanced oil/gas recovery. The research community and industry are progressively converging to a conclusion that CO₂ sequestration has severe limitations for the value proposition. Alternatively, creating diverse demand markets and revenue streams for the recovered almost-pure CO₂ may prevail over CO₂ sequestration option and improve the economic feasibility of this climate change mitigation approach. As such, research in the carbon capture and management field is seen to be shifting towards CO₂ utilization, directly and indirectly, in energy and chemical industries.

In this paper, we have critically reviewed the literature on carbon capture, conversion, and utilization routes and assessed the progress in the research and developments in this direction. Both physical and chemical CO₂ utilization pathways are studied and the principles of key routes are identified. The literature is also probed in addressing the process integration scenarios and the performance assessment benchmarks.

1. Introduction

Today, climate change is attributed to the emission of certain so-called “anthropogenic” greenhouse gases (GHGs) including carbon dioxide, methane, nitrous oxide, hydro-fluoro-carbons (HFCs), per-fluorocarbons (PFCs), and sulfur hexafluoride (SF₆). Breakdown of the natural greenhouse effect by contributing gases include: water vapor (36–70%), carbon dioxide (9–26%), methane (4–9%) and ozone (3–7%) [1]. Since the Industrial Revolution and the exploration of fossil fuels, the emission of anthropogenic GHGs has steadily increased. According to the Intergovernmental Panel on Climate Change (IPCC) fifth assessment report “human influence on the climate system is clear, and recent

anthropogenic emissions of greenhouse gases are the highest in history.” [2]. Among GHGs, carbon dioxide (CO₂) is the most important in terms of quantity emitted.

Carbon dioxide is one of the main components of the Earth’s texture that prominently exist in the core, crust, and also in the atmosphere. Fig. 1 shows a simple schematic of the carbon cycle in the interchange between the Earth and the atmosphere. It can be dissolved in water, reacted with other substances, solidified in carbonated rocks, or freely exist in the atmosphere. This cycle had established its equilibrium over millions of years until the era of the Industrial Revolution. Since then, the rate of CO₂ release increased initially with less than 1 part per million per year (ppm/y) till the 1960s and then more than 2 ppm/y afterward [3].

Abbreviations: Ar, argon; ASU, air separation unit; ATR, auto-thermal reforming; BiR, bi-reforming; BPO, benzoyl peroxide; BTL, biomass to liquid; CCS, carbon capture and storage; CCU, CO₂ capture and utilization; CCUS, CO₂ capture sequestration and utilization; CFA, carbonated fly ash; CTL, coal to liquid; DFT, density functional theory; DMC, dimethyl carbonate; DME, dimethyl ether; DMR, dry-methane reforming; EB, ethylbenzene; EC, ethylene carbonate; EGR, enhanced gas recovery; EO, ethylene oxide; EOR, enhanced oil recovery; FPSO, floating production, storage and off-loading; FT, Fischer-Tropsch; GHG, greenhouse gases; GTL, gas-to-liquid; HEN, heat exchanger network; HFC, hydro-fluoro-carbons; IPCC, Intergovernmental Panel on Climate Change; LCA, life-cycle assessment; LHV, lower heating value; MEA, mono-ethanol-amine; MOF, metal-organic frameworks; MPILs, polyionic liquids; NBS, *N*-bromosuccinimide; NSoR, non solar; OCRM, oxidative CO₂ reforming of methane; OT, once through; PC, propylene carbonate; POX, partial oxidation; PTG, power-to-gas; RB, reverse-Boudouard; RC, recycle; RWGS, reverse water gas shift; SMR, steam-methane reforming; SNG, synthetic natural gas; Syngas, synthesis gas; TMC, tri-methylene carbonate

* Corresponding author at: Faculty of Information Technology, Monash University, Melbourne, VIC, 3145, Australia.

E-mail address: kr.khalilpour@monash.edu (K. Rajab Khalilpour).

<https://doi.org/10.1016/j.jece.2018.08.065>

Received 28 January 2018; Received in revised form 11 July 2018; Accepted 27 August 2018

Available online 03 September 2018

2213-3437/ © 2018 Elsevier Ltd. All rights reserved.