IEAGHG Information Paper 2017-IP57; A Review of Hybrid CO_2 Capture Processes

Although CCS has been widely recognised as one of the mitigation pathways to cut down CO_2 emissions, the energy penalty associated to carbon capture technologies is still high. An overview of the energy investment points for each technology is summarised in the table below. For example, the integration of an absorption-based process with MEA (3.0-4.5 GJ/ton CO_2) in a power plant would decrease the power plant efficiency by approximately 10% and the 80% of the energy required for the capture would be invested in the solvent regeneration. Enhanced systems with lower energy consumption for regeneration (saving 1GJ/ton CO_2) would potentially decrease this efficiency penalty by 2%. For example, the use of Cansolv (2-2.3 GJ/ton CO_2, electric energy) has reported an efficiency reduction of approximately 8% when used together with a proper heat integration strategy [2].

Technology	Driving Energy Factors
Absorption	Thermal energy needed for regeneration Electric energy for the machine operation
Adsorption	Electric energy to generate pressure difference(PSA) Thermal energy to provide desorption heat (TSA)
Membranes	Electric energy for compressor or vacuum pump
Cryogenic and hydrate separation	Electric consumption for conditions and operation

A potential alternative is the use of hybrid systems, which combine two/three types of primary capture systems and can mitigate the disadvantages shown by the single systems. In this regard, Song et al. [1], have collected available information on hybrid systems. As a starting point, a table of available hybrid technologies, their advantages and challenges is shown on page 3. Linking this review on hybrid technologies to the IEAGHG report in 2014 (see http://ieaghg.org/docs/General_Docs/Reports/2014-TR4.pdf), membrane-cryogenic systems and adsorption-catalysis were identified as emerging technologies at TRL6 and 1 respectively, with a potential to reduce LCOE by 30 and 7% compared to chemical absorption with MEA. Cryogenic capture was classified as TRL3 (expected to advance quickly) and low temperature separation was catalogued as very low TRL.

Within the list of hybrid technologies included, three of the membrane hybrid systems stand out due to their low electric energy requirements: membrane- pressurized water scrubbing, low temperature-membrane-cryogenic, and membrane contactor, with 0.64, 0.78-0.87 and 0.86 GJ/ton CO_2 (electric consumption). In this group, membrane contactor is the most advanced one. Advantages compared to absorption system comprise the reduction of solvent evaporation and emissions, and lower capital cost and footprint. Nevertheless, the selection of the membrane material is key to avoid stability issues and wetting phenomena in long-term operation. PCCC4 recently reported some results, and current funded NETL projects include this configuration (see http://ieaghg.org/docs/General_Docs/Information_Papers/2017-IP51.pdf). Recent advanced systems are being tested in the NCCC facilities (0.5 MWe) and fast advance of this hybrid technology is expected in the coming years, based on the recent scaled-up and many research groups combining novel membrane materials and innovative amine solutions.

Still, most of the technologies with higher potential in cost reduction are at low TRL and must be proved at proper scale. In addition, those solutions are very site-specific and the configuration (series, parallel and integration arrangements) must be optimized based on the operation conditions. Due to those factors, although promising, hybrid technologies must be studied further.

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For more information about this review, see:

[1] Song C., Liu Q., Ji N., Deng S., Zhao J., Li Y., Song Y., Li H. (2018) Alternative pathways for efficient CO2 Capture by hybrid processes- A review. Renewable and Sustainable Energy Reviews 82, pp. 215-231

[2] Just P.E., Mirfendereski Y., Geuzebroek F. (2009). Cansolv Technologies: The Value of Integration. http://www.ieaghg.org/docs/General_Docs/12%20cap/3-3%20Sec.pdf

Hybrid system	Advantages	Challenges
Absorption-based		
Membrane contactor	• High selectivity due to the absorption • Modularity and compactness through the membrane configuration • Effective at low CO_2 concentration	• Increased mass transfer resistance • Issues related to the membrane performance: wetting, fouling and plugging • Thermal and chemical stability
Absorption-membrane	• Series arrangement: o Reduction of regeneration energy o Mitigation of amine emissions • Parallel arrangement: o Reduction of capital costs due to the reduction of the absorber	• Capture cost is still high • Influence of O_2 dilution in the membrane performance
Absorption-adsorption	• Higher CO_2 carrying capacity • Lower heat capacity due to the lack of water	• Potential high pressure-drop across the absorber • Need to use advanced sorbents • Potential to block the pore and collapse its structure (reduction of porosity)
Adsorption-based		
Adsorption-catalysis	• Increase on the CO conversion • Lower capital costs as it needs just one reactor instead of two • H_2 production is enhanced	• Advanced sorbents are needed • The sorbents deteriorate and its reactivity is decreased
Adsorption-catalysis-membrane	• Enhanced conversion of CO to CO_2 and H_2 • Lower capital costs as the process is carried out in one unit and with lower membrane area • Lower operation cost due to lower steam usage • Higher H_2 purity	• High energy requirement for regeneration due to high temperature needed, which can also potentially affect the catalyst stability • Poison the membrane caused by CO • It is needed to enhance the selectivity H_2/CO_2 • The integration of this technology is still challenging
Adsorption-cryogenic	• Reduction of total energy consumption • Higher CO_2 purity stream • Liquid CO_2 for supercritical state	• Pre-treatment of the gas (drying) • High energy consumption in low temperature unit
Adsorption-membrane	• Enhanced process energy efficiency • Higher CH_4 purity Stream • High CO_2 purity stream	• Heat exchanger is expensive
Adsorption-hydrate	• Enhanced mass transfer between gas and liquid phases • Reduction on energy requirement due to less mechanical agitation	• A promoter is needed to facilitate the hydrate formation • CO_2 recovery is low
Membrane-based		
Membrane-cryogenic	• Reduction of the compression work • Reduction of cost of CO_2 avoided • Lower capital cost due to smaller cryogenic equipment • Lower operation cost • Can be combined with other capture systems	• It is needed an O_2 enrichment unit
Membrane-absorption	• Reduction of energy penalty • High purity CO_2 stream	• Still high energy consumption • Deterioration of the membrane • Requirements of the membrane materials
Low temperature-based		
Cryogenic-hydrate	• Lower energy requirement and lower cost compared to standard cryogenic distillation	• Low CO_2 recovery • It is still an immature technology
Low temperature membrane-cryogenic	• Increase on the CO_2/N_2 selectivity • Minimal CO_2 permeance loss • Enhanced separation compared to commercial modules	• Increase of capital cost • Sensible to moisture
Low temperature absorption	• High CO_2 purity in pre-combustion • Lower energy requirement in post-combustion	• It is needed a better understanding of the dissociation of the CO_2 hydrate • Still needed to reduce regeneration energy • Absorbents can be volatile
Phase of CO_2 product	• Reduction of energy consumption • Potential to recover latent heat	