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Advances in CO_2 utilization technology: A patent landscape review

R.S. Norhasyima[a,b,*], T.M.I. Mahlia[a,c]

[a] Department of Mechanical Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia
[b] PETRONAS Research Sdn Bhd, Kawasan Institusi Bangi, 43000 Kajang, Selangor, Malaysia
[c] School of Systems, Management and Leadership, Faculty of Engineering and Information Technology, University of Technology Sydney, NSW 2007, Australia

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ABSTRACT

There is rising concern on the increasing trend of global warming due to anthropogenic CO_2 emission which steers progress of carbon capture and storage (CCS) projects worldwide. However, due to high cost and uncertainties in long term geological storage, there is a growing inclination to include utilization, which re-use the CO_2, hence carbon capture utilization and storage (CCUS). Additionally, it is expected to generate income to offset the initial costs. This study methodically review patents on CO_2 utilization technologies for CCUS application published between year 1980–2017. It was conducted using the Derwent Innovation patent database and more than 3000 number of patents was identified. The patents identified are in the field of enhanced oil recovery (EOR) and enhanced coal-bed methane (ECBM), chemical and fuel, mineral carbonation, biological algae cultivation and enhanced geothermal system (EGS). Over 60% of these patents were published since the last 10 years, and a sharp increase in patents were seen in the last 5 years (~38%). The top major patent types are patents granted in the United States (US), China (CN) and Canada (CA) which makes of 3/5 of the overall patent type found. Recent patents published include enhancements to the state-of-the-art technologies and hybrid concepts such as in photo-bioreactor in algae cultivation, chemical reaction and EGS. From this study, it was found that further research for the best CO_2 utilization method which fulfil the need of an economic, safe, non-location dependent and environmentally friendly whilst efficiently mitigate the worldwide global warming issue is much needed.

1. Introduction

Limiting the increase of anthropogenic carbon dioxide (CO_2) emissions in the environment is a major challenge facing the world today. Hence, there is a vital need to assess the growing worldwide concern about global climate change. CO_2 generally originated from flue gas from fossil fuel combustion, biogas from anaerobic digestion, product of coal gasification and natural gas streams [1–4]. According to BP energy statistics, in the year 2016 there were 33,432.04MT of CO_2 emission worldwide [5]. An assessment conducted by The Intergovernmental Panel of Climate Change (IPCC), concluded that the CO_2 emissions should be decreased by at least 50% to limit the escalation of the global average temperature to 2 °C by 2050. International Energy Agency (IEA) presented models of technology mix which are essential to meet the 2 °C scenario. The model shows that in order to achieve the targeted scenario, CCUS will need to contribute at least one-sixth of global CO_2 emission reductions by 2050, as well as 14% of the cumulative emissions reductions from 2015 to 2050 as compared to a business-as-usual [6].

CCUS is a methodology to separate CO_2, then utilize CO_2 to produce valuable products and techniques to store produced CO_2, commonly from power generation, industrial processes and even high CO_2 gas fields. The IPCC report stated that without CCUS implementation, the overall cost required to mitigate global climate change may increase up to 138% and there is great challenge to achieve the targeted 2 °C scenario [7]. Various international agreements have been established to ensure that CCUS will play an important role for an economically sustainable route for CO_2 emissions cut required to limit the global climate change rise [8]. More recently, the Paris Agreement of 2016 was established to further accelerate the worldwide response to the threat of climate change by keeping a global temperature rise this century by limiting the temperature rise even further to 1.5 °C [9]. This effort requires even more effective actions to combat climate change, especially on the mitigation for CO_2 emission reduction worldwide. Therefore, new technologies are needed to be developed as one of the critical methods to mitigate the global warming issue [10]. Apart from international agreements, a global competition was introduced to combat CO_2 emission. NRG Canada's Oil Sands Innovation Alliance (COSIA)

* Corresponding author at: Department of Mechanical Engineering, Universiti Tenaga Nasional, 43000, Kajang, Selangor, Malaysia.
E-mail addresses: norhasyima.rahmad@petronas.com.my, PE20454@utn.edu.my (R.S. Norhasyima), indra@uniten.edu.my (T.M.I. Mahlia).

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Carbon XPRIZE which began in September 2015 and will end in March 2020, is a US$ 20 Million international competition introduced to develop game-changing technologies that will convert CO_2 emissions from various sources into valuable product which will ultimately address climate change issue [11].

An extensive diversity of utilization techniques are being improved and developed, from technologies to make use of CO_2, increasing the design life of near depleted oil fields, working fluid in geothermal systems to energy storage. All these techniques are still under study or an early stage of development. The development stages of the CCUS technologies can be described using technology readiness level (TRL) scale classification from level 1 to level 9 [12]. Furthermore, selling captured CO_2 provides revenues to partly benefit and overcome the fairly high capital expenditure and financial risks associated with CCUS projects [8]. In addition, CCUS avoids the problems of high costs as well as public acceptance which previously hinders CCS implementation [13].

The CO_2 utilization potential should be of a scale proportionate with future CO_2 capture technology and requirements from large industrial sources and power generation [14]. In this paper, a patent landscape for CO_2 utilization technologies for CCUS application was investigated. A minimum limitation of 5 MTPA (million metric tonnes per year) of CO_2 utilization potential was applied in order to ensure CCUS to be successfully materialized and economically viable [15]. Potential CO_2 market demand and utilization method is presented in Table 1. Five (5) technologies have been shortlisted and identified as a potential CO_2 utilization method for CCUS application (Fig. 1).

In reference to Fig. 1, CO_2 utilization methods via food processing and beverage carbonation packaging was excluded from the listing although both methods have CO_2 demand of more than 5 MTPA. Since both methods are conventional industries with stable rate, the forecasted CO_2 demand growth is expected not to surpass 5 MTPA in the near future. Hence, both methods has been omitted from the CO_2 utilization methods for CCUS application listing.

2. Methodology for carbon utilization patent search

Worldwide, patents have been recognized as rich sources of data for competitive edge analysis, disruptive technology forecasting, and global management for invention portfolios. Due to high prospect of patents as key indicator of numerous technology development measurements and as economic scale, patent analysis is very important to corporate entities as well as significant to academic study [16].

This study utilizes the Derwent Innovation (formerly known as Thomson Innovation) (https://www.derwentinnovation.com/login/) [17] search and analytics platform to search for patents. Derwent Innovation offers over 23 million basic inventions and more than 51 million patents from major patent authorities, specific nations and proprietary sources exclusively with worldwide patent coverage and has access to patent records from over 50 patent issuing authorities, with English translations from 30 languages.

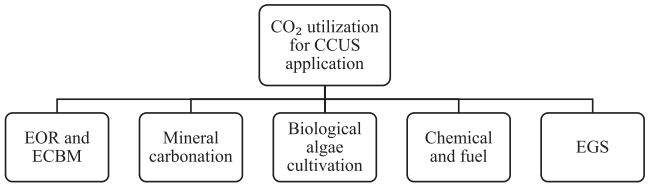

Fig. 1. CO_2 utilization methods for CCUS application.

Table 2
Search strategy in Derwent Innovation search and analytics platform.

CO_2 utilization methods	Keyword terms
EOR and ECBM	Search (CO_2 AND enhanced oil recovery (EOR)) and (enhanced coal-bed methane (ECBM)) [Title, Abstract, Claims]
Mineral carbonation	Search (CO_2 AND mineral carbonation AND carbonates OR concrete) [Title, Abstract, Claims]
Biofuels from microalgae	Search (CO_2 AND biofuels AND microalgae" [Title, Abstract, Claims]
Fuel and Chemical	Search (CO_2 AND conversion chemical/s) and (CO_2 AND fuel/s) [Title, Abstract, Claims]
EGS	Search "CO_2 AND enhanced geothermal system (EGS)" [Title, Abstract, Claims]

Using the Derwent Innovation search and analytics platform tool, an advanced patent search using keywords in patent titles, abstract or claims for CO_2 utilization options for CCUS application was performed. The search strategy for patents on CO_2 utilization method for CCUS application was carried out using specific keyword search terms (Table 2). Data were then extracted and analyzed using the Microsoft Office Excel 2013 software program (Microsoft Corporation, Redmond, Washington, USA). The extracted data were then tabulated into Microsoft Excel format spreadsheet and dashboard with data including; title of patents, applicant/s, inventor/s name, priority date of patents, International Patent Classification (IPC), abstract and claims. All listed patents details were then systematically reviewed and grouped into the corresponding category.

This systematic patent review process as illustrated in Fig. 2 was conducted based on the PRISMA statement [18]. A patent search was conducted in July 2017, and the patent abstracts or the full patents were carefully reviewed, grouped and analyzed. The search initially retrieved 10,200 patents with 6221 being excluded as duplicate patents. Then the title, claim abstract of each patent identified were evaluated to determine whether the patents should be considered for further analysis. Out of 3979 patents selected, 805 was excluded since it was not for CO_2 re-use and another 172 was excluded since it did not meet the eligibility criteria for CCUS application. A total of 3002 patents on CO_2 utilization method for CCUS application was finalized. After the evaluation, the full patent was screened in order to extract the

Table 1
Potential CO_2 market demand [15].

CO_2 utilization method	Potential CO_2 demand (MTPA)	CO_2 utilization method	Potential CO_2 demand (MTPA)
Enhanced oil recovery (EOR) & Enhanced coal bed methane (ECBM)	30-300	Horticulture	1-5
Mineralization	> 300	Pulp and paper processing	< 1
Fuel & Chemical including urea yield boosting	> 300	Inerting	< 1
Biofuel from algae	> 300	Steel manufacture	< 1
Enhanced geothermal system (EGS)	5-30	Metal working	< 1
Beverage carbonation	~14	Supercritical CO_2 as solvent	< 1
Food processing, packaging	~15	Electronics	< 1
Power generation – CO_2 as working fluid	< 1	Pneumatics	< 1
Water treatment	1-5	Welding	< 1
Wine making	< 1	Refrigerant gas	< 1
Coffee decaffeination	1-5	Fire suppression technology	< 1
Pharmaceutical processes	< 1		