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Proceeding Paper

Evaluation of Potential Carbon Dioxide Utilization Pathways in Uzbekistan †

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Abstract: Reaching net-zero emissions by the middle of this century requires the implementation of massive carbon dioxide (CO_2) emission reduction strategies along with the reduction of other greenhouse gases on both global and country scales. Thus, carbon capture, storage, and utilization (CCSU) is a promising technology in combination with renewable energy transition. Currently, CO_2 utilization has attracted much attention from the scientific community worldwide, since it can improve the economic viability of CCSU deployment by creating a market for the recovered CO_2 stream. In this study, a brief assessment and comparison of potential CO_2 utilization pathways in Uzbekistan, including CO_2-to-chemical/fuel conversion, CO_2 bio-fixation/mineralization, and the direct use of CO_2, such as for enhanced hydrocarbon recovery (EHR), are conducted considering the CO_2 stationary sources and site-specific conditions of the country. In addition, possible challenges and opportunities for large-scale CO_2 utilization routes are also discussed. According to this assessment, there is great potential for the direct use of CO_2 as a process-boosting agent for EHR in more than 22 major natural gas, crude oil, and coal reservoirs. Moreover, methanol and urea production processes can also create huge market demand for recovered CO_2 as long as the conventional CO_2 production processes are replaced by sustainable ones.

Keywords: decarbonization; climate change; carbon capture; CO_2 utilization; CO_2 recovery; Uzbekistan

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1. Introduction

The rising concentration of carbon dioxide (CO_2) in the atmosphere has emerged as being of paramount concern to the global community. In order to mitigate the effects of greenhouse gas (GHG) emissions and align with the goals of the Paris Agreement, we should explore all available pathways to be as close as possible to net-zero emissions by 2050. In this context, carbon dioxide capture and utilization (CCU) emerges as a promising strategy by not only reducing emissions but also transforming CO_2 into valuable resources or reusing it for other applications [1].

The Republic of Uzbekistan (Uzbekistan), located in Central Asia and one of the two double-landlocked countries in the world, has been experiencing significant demographic and economic growth in recent years. In response to these increases, there is high demand for expanding the industrial sectors in Uzbekistan, which is driven primarily by the country's natural resources such as natural gas, coal, and crude oil. Meanwhile, Uzbekistan plans to cut its GHG emissions per unit of gross domestic product by 35% by 2030 from a base year of 2010 [2]. Additionally, Uzbekistan pledged to reach carbon neutrality by 2050 through different decarbonization pathways [3]. In this scenario, there is a strong necessity for the estimation and analysis of the CO_2 capture potential of Uzbekistan from large stationary sources and possible CO_2 utilization pathways considering the country's site-specific conditions.

Carbon capture, storage, and utilization (CCSU) is a technology that enables us to capture the CO_2 from fossil fuel-fired large point sources such as power plants, cement factories, steel and iron industries, crude oil and natural gas refineries, and petrochemical plants. Once the CO_2 is captured through different separation techniques, it is then compressed at high pressure and transported to a storage or utilization site [4]. There are two—direct and indirect—methods for the utilization of captured CO_2. In direct utilization, the captured CO_2 is used in its physical form without undergoing chemical transformation. This can be applied in several industries including enhanced hydrocarbon recovery (her), food and carbonated beverages, textiles, and greenhouse agriculture. In indirect use, the captured CO_2 undergoes chemical or biological processes that convert it into multiple valuable products. This can involve broader pathways such as CO_2-to-chemicals and -chemical feedstock (methanol, urea, organic acids, ethylene and propylene glycol, etc.), CO_2-to-synthetic fuels (methane, dimethyl ether, kerosene, diesel, gasoline, etc.), CO_2 mineralization (construction aggregates, cement, magmatic rock, etc.), CO_2-to-bio-products (biofuels, bioplastics, bio-additives, etc.), and the carbonation of industrial waste [5].

In recent years, due to the low market value of captured CO_2 which prevents the global application of CCSU, more research and investigations are focusing on CO_2 utilization and its valorization. This paper briefly discusses the potential CO_2 utilization pathways in Uzbekistan and their comparison based on several environmental, economic, and technological indications.

2. Shortlisting Procedure

Given the diverse array of over a hundred CO_2 conversion pathways and numerous CO_2 direct utilization routes available, our approach involves shortlisting more technologically mature and commercially viable options which will undergo a comprehensive analysis, taking into consideration the specific environmental and resource conditions in Uzbekistan. The four shortlisted pathways, including CO_2-to-methanol and -urea conversion, CO_2-to-enhanced oil/gas recovery, CO_2 use in cement production, and CO_2-to-bio-fixation are discussed with their opportunities and challenges from economic, environmental, and scalability points of view. This assessment is limited to evaluating CO_2-to-fuel conversion due to it having the lowest carbon retention time compared to the others.

3. Potential CO_2 Utilization Pathways

As mentioned earlier, the captured CO_2 presents valuable opportunities for utilization within Uzbekistan's industries through two distinct pathways: direct and indirect applications. Direct utilization, which involves the non-conversion of captured CO_2, finds prominent use primarily in enhancing hydrocarbon recovery. This is especially relevant due to the presence of several natural gas and oil reservoirs in the region, as well as its application in the textile fabrication industries.

On the other hand, indirect utilization, which entails the conversion of captured CO_2, plays a vital role in sectors such as the chemical and nonmetallic industries, with a particular focus on applications within the cement industry. The subsequent sub-sections will provide detailed insights into these specific indirect utilization pathways and their significance.

3.1. CO_2-to-Methanol and -Urea

All among the CO_2 conversion routes, CO_2-to-methanol and -urea production are, so far, not only the most mature technologies but also in highest demand in the world market, with annual consumption of over 110 Mt per year [6].

Methanol is a crucial chemical feedstock for various industries, including chemicals and fuels. The main methanol-derived products are formaldehyde, acetic acid, dimethyl ether, and methanol fuel. Methanol to Olefin (MTO) is as an emerging technology, another promising pathway that enables us to obtain various high-value products such as polypropylene, polyethylene, ethylene vinyl acetate, and polyethylene terephthalate. However, from an environmental point of view, the production of hydrogen, the main reactant for CO_2 to make methanol, should be sustainable through the use of water electrolysis or fossil fuel-based production with CCSU. The following equation (1) is the base reaction of CO_2-to-methanol conversion [7].

$$CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O,\ \Delta H_{298\ K} = -49.4\ \text{kJ/mol} \quad (1)$$

Uzbekistan is considered a leading country in Central Asia in methanol production, and its export accounts for 67% of demand [8]. Additionally, Uzbekistan's Gas Chemical Complex has signed an agreement with Air Products to build an MTO facility by the end of 2025, which will be constructed in the Karakul Free Economic Zone in Uzbekistan's Bukhara region. The total capacity of this facility can reach up to 1.34 million tons annually [9].

Urea production from CO_2 could also be viable option in the case of Uzbekistan, as the country's economy is highly dependent on agriculture. Urea is commonly used in the fertilizer industry due to its low transportation cost and rich nitrogen sources. Moreover, it can be used as a primary source for the production of several essential chemical compounds, including a variety of polymers and resins. Since urea is obtained from the reaction between ammonia and CO_2 (see reactions (2) and (3) below), the CO_2 uptake potential of urea production is relatively high at 0.733 tons of CO_2 per ton of urea [7].

$$2NH_3 + CO_2 \leftrightarrow NH_2OCONH_4, \quad (2)$$

$$NH_2OCONH_4 \leftrightarrow NH_2CONH_2 + H_2O. \quad (3)$$

Uzbekistan has already built a facility to produce urea and ammonia under the Navoiyazot Chemical Complex with an annual capacity of 660 thousand tons of ammonia and 577 thousand tons of urea [10]. Furthermore, a new ammonia-based fertilizer plant with a total capacity of 1089 Mt of urea and ammonia is under construction in Yangiyer, Sirdaryo Region, and expected to be completed by 2025 [11]. Among several conversion methods, one important advantage of urea production using captured CO_2 is the utilization of post-combustion flue gas to obtain CO_2 and nitrogen, the primary components required for ammonia production. As a result, the generation of urea from ammonia reactions with CO_2 taken from combustion exhaust gases would boost the financial viability of a CO_2 capture unit [7]. However, the only concern about boosting urea production using captured CO_2 is its environmental benefit which is under question due to the release of CO_2 into the atmosphere as the fertilizer is used.

3.2. CO_2-to-EHR

Since the current low carbon costs fail to motivate investment in CCS, several industry experts believe that EHR projects are the only viable short-term use for significant CO_2 levels. CO_2 injection for enhanced oil recovery (EOR) and enhanced gas recovery (EGR) is growing in the petroleum and natural gas industry as it both utilizes captured CO_2 and boosts oil/gas production, preventing CO_2's release into the atmosphere [12]. This is vital in the transition to a more sustainable and low-carbon-energy future, particularly in terms of efficiently utilizing existing oil and gas resources while addressing climate change concerns.

For a preliminary assessment of CO_2 storage, deep underground and oil, coal, and gas reservoirs are the first places where there is sufficient capability for a massive amount of captured CO_2 to be permanently stored and utilized. All major natural gas, coal, and crude oil fields of Uzbekistan are summarized in Figure 1.

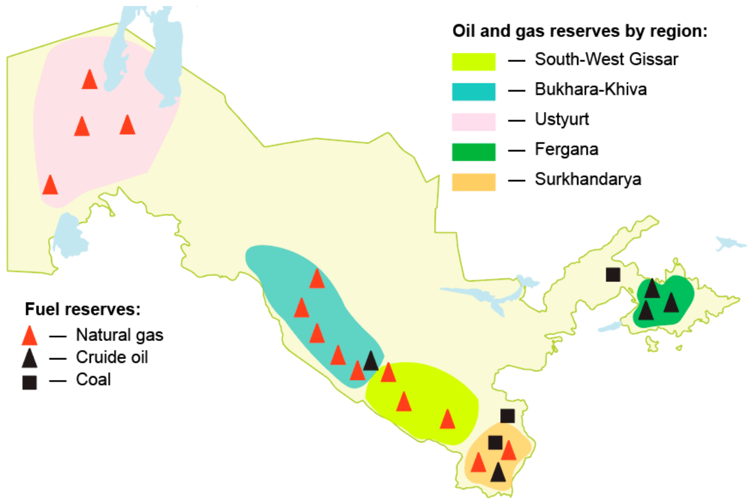

Figure 1. Main large oil and gas reserves in Uzbekistan by region.

According to Figure 1, Uzbekistan has great potential for the utilization of captured CO_2 through the EOR, EGR, and enhanced coal bed methane (ECBM) pathways. The availability of reservoirs in neighboring countries also enables the possibility for the offshore storage of captured CO_2 while avoiding long-distance transportation costs. Since EOR is considered the only option so far as a fully mature technology to store massive amount of CO_2 while allowing a partial return on investment, onshore and offshore EOR injection of CO_2 could be the first targets in the utilization of CO_2 in Uzbekistan.

3.3. CO_2 Mineralization

Carbon mineralization, also known as CO_2 mineralization is a process that includes the transformation of CO_2 from gaseous state to solid by converting it to the mineral forms using chemical and geological materials. In the carbonization process, CO_2 reacts with certain minerals such as magnesium and calcium silicates resulting the formation of stable magnesium carbonates and calcium carbonates [13]. It can then be used as building materials as construction aggregates, concrete curing, and cement production. One of the greatest advantage of this method is to sequester the CO_2 permanently for thousands of millions of years.

In the case of Uzbekistan, with the growing population and urbanization, there is huge demand for construction materials and aggregates [14]. Calcium and magnesium carbonates, which can be found naturally in rocks and inorganic salts, mostly in the regions of Karakalpakstan, Fergana Valley, the Tashkent suburbs, and Navoi, are the traditional precursors used in the manufacturing of cement. It is worth noting that captured CO_2, once it has been transformed into calcium or magnesium carbonates, can operate as an alternate input material or precursor for this manufacturing process. However, the limited availability of suitable mineral resources, the lack of geological assessments, and slow reaction kinetics hinder the application of CO_2 mineralization in the near term.

3.4. CO_2-to-Bio-Fixation

One of the feasible strategies for combatting CO_2 emissions from point sources is the biological pathway. This biological method provides natural CO_2 incorporation into biomass at a relatively low cost in terms of energy. Photoautotrophy and chemolithotrophy are natural mechanisms that have resulted in the consumption of CO_2 biologically. Algae-based CO_2 utilization, among others, can be a promising route that uses photosynthesis to capture CO_2 from flue gas for carbon fixation, particularly in the availability of waste water resources [15]. Microalgae can be cultivated in a closed system (photobioreactor) and an open system (raceway pond). In terms of algae applications, they are divided mainly into two categories [16]:

- "Bioenergy": biodiesel, biogas, bioethanol, bio-jet fuel, etc.
- "Non-energy bio-products": protein, pigments, carbohydrates, biomaterials, animal feed, etc.

Considering the large CO_2-emitting sources in Uzbekistan, particularly natural gas-fired combined-cycle power plants, which account for more than 85% of the energy sector and have low CO_2 concentrations in their waste streams, CO_2 microalgae cultivation could be promising pathway as this technology can capture and utilize the CO_2 simultaneously [17]. While the significant space demands of this approach are manageable, certain locations in the country may face challenges related to the availability of water or wastewater [18]. In such cases, there might be a requirement for the installation of closed-loop photobioreactors, which tend to be more costly.

4. Discussion

In this section, we compare five different CO_2 utilization methods in terms of their environmental benefits, scalability, maturity, and economic feasibility in the context of Uzbekistan, without specific metrics. Taking into account the various aspects and criteria for each unique situation and technology presents challenges in achieving a precise comparison. Therefore, this discussion aims to offer a broader understanding of the feasibility of each approach. Figure 2 represents a comparison of the CO_2 utilization pathways in Uzbekistan based on four different parameters.

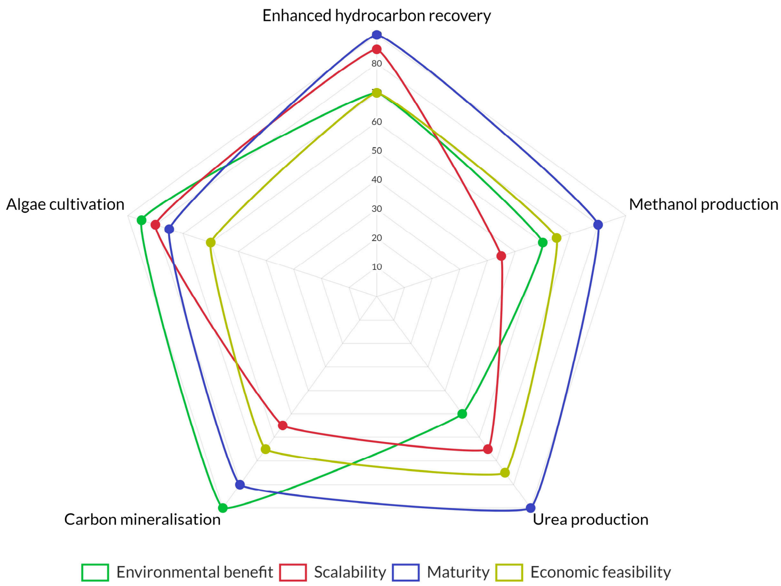

Figure 2. A general comparison of potential CO_2 utilization pathways in Uzbekistan based on four different parameters.

From an environmental point of view, the CO_2-to-algae cultivation and carbon mineralization pathways are seen as the most promising, but these technologies have not reached full maturity yet [19]. The high energy intensity of the mineral carbonation process and the high cost of photobioreactors along with control challenges prevent these utilization routes from undergoing massive deployment. In terms of the urea and methanol production from captured CO_2, they can be economically viable, covering part of the capture costs, since the methanol-to-olefin and fertilizer markets are facing a rapid improvement in the country. However, there is a strong necessity to solve the problems associated with the logistics of exporting overseas and making the process more sustainable. As for CO_2 injection as a process booster into oil and gas reservoirs, in the near term, it could be the most promising route regarding the conditions of Uzbekistan, as long as the natural gas and oil prices on the world market stay stable. Nevertheless, the main concerns for the implementation of EOR and EGR in the country are the evaluation of the environmental benefit, as the process leads to an increase in the production of fossil fuels, and the availability of open data sources on the current state and technical characteristics of the reservoirs.

5. Conclusions

In this paper, possible CO_2 utilization pathways in Uzbekistan are discussed with a general comparison based on available resources, scalability, and environmental and economic viability. We explore the potential opportunities and challenges that could lay ahead by examining different approaches and technologies within the context of Uzbekistan. Currently and in the near term, CO_2-to-enhanced hydrocarbon recovery could be the most feasible option until we find more sustainable and large-scale CO_2 conversion pathways. Algae cultivation may also be viable as long as the capital costs of the reactors are reduced or the availability of wastewater is maintained. However, there is huge demand for further investigation of possible pathways while taking into account the existing resources and limitations.

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