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King Abdullah Petroleum Studies and Research Center

International Energy Agency

Decarbonizing Oil: The Role of CO_2 Enhanced Oil Recovery (CO_2-EOR)

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About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is a non-profit global institution dedicated to independent research into energy economics, policy, technology and the environment, across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

Legal Notice

Key Points

The International Energy Agency (IEA) and KAPSARC co-hosted an expert workshop on the potential of advanced carbon dioxide (CO_2) enhanced oil recovery (CO_2-EOR) to decarbonize oil production. The workshop focused on the potential for using CO_2-EOR for CO_2 storage and increasing oil production, also known as advanced CO_2-EOR. Over the course of the two-day meeting, over 50 participants from government, industry and academia examined the current status of CO_2-EOR, explored the economic and environmental benefits of advanced CO_2-EOR and discussed the challenges facing its widespread adoption.

The existing U.S. industry could utilize significantly higher volumes of CO_2 if they were available at affordable prices. Elsewhere, CO_2 is often not available in the volumes demanded by enhanced oil recovery (EOR) projects.

The effectiveness of CO_2 floods is critically dependent on reservoir miscibility, CO_2 sweep efficiency and the purity of the CO_2 gas used. Displacing water from reservoirs can increase CO_2 storage volume. Fiscal incentives to mitigate carbon influence actual volumes and rates of CO_2 utilized.

Opportunities to lower the carbon intensity of oil production exist across the value chain with varying degrees of cost-effectiveness and mitigation potential. Measures taken today to reduce the carbon intensity of petroleum supply will be beneficial to the climate.

Greater fiscal and regulatory incentives are needed to begin scaling advanced CO_2 storage through EOR around the globe. A viable and large-scale CO_2-EOR industry depends upon significant capital investments for CO_2 capture and transportation infrastructure. Policy consistency and predictability combined with targeted subsidies will help to achieve this goal.

Summary for Policymakers

Under the Paris Agreement's 'well below 2 °C' climate target, countries have committed to work towards development paths that, over time, become carbon neutral. Of the key emitting sectors, carbon dioxide (CO_2) emissions from transportation are the most challenging to reduce cost-effectively. According to the International Energy Agency (IEA) Reference Technology Scenario, CO_2 emissions in this sector could reach 14 billion tonnes by 2050. Storage-focused CO_2-EOR can help to cost-effectively reduce the carbon footprint of oil use in the transport sector and support other decarbonization options. The life cycle of greenhouse gas (GHG) emissions associated with a barrel of oil range from around 400 to 900 kilograms (kg) CO_2 equivalent (eq), and depend on a wide range of factors. CO_2-EOR can effectively lower the carbon intensity of oil production across the value chain. While wider concerns persist about the petroleum industry using CO_2-EOR to extend fossil fuel use, oil and gas will continue to be major contributors to energy supply for decades to come. It is essential, therefore, to reduce the carbon intensity of petroleum supply in order to benefit the climate.

Currently, EOR projects use about 80 million tonnes of CO_2 per year, almost all of which becomes permanently trapped in oil reservoirs. Of this number, about 20 million tonnes are captured from a variety of activities such as natural gas processing, ethanol and fertilizer production, and – notably – power generation and steelmaking. While virtually all of these activities take place in the U.S., the potential for CO_2-EOR storage outside North America is significant and currently estimated to correspond to an economic storage potential in the order of 40 gigatonnes of CO_2.

Conventional CO_2-EOR operations use about 300 kg of CO_2 per incremental barrel of produced oil. These projects look to optimize their return on investment rather than maximize CO_2 storage. However, CO_2-EOR can be configured to co-exploit hydrocarbon production and storage. The amount of CO_2 that can be stored via 'advanced' CO_2-EOR practices will be determined by reservoir characteristics, wells and infrastructure design and operating choices and by economic variables. These include the oil and CO_2 prices the operator can obtain from hydrocarbon production and for CO_2 storage. Additionally, the availability of CO_2 is a critical barrier for large-scale EOR deployment and plays a key role in determining how much CO_2 is stored during the EOR process.

The value proposition for CO_2-EOR may be different in different countries. While the emission reduction objective may be driving CO_2-EOR deployment in some countries, in other countries the selling point for CO_2-EOR could be to free up natural gas that would otherwise be reinjected, job creation, or the effective use of domestic hydrocarbon resources. Regulatory requirements, technological capabilities and the supply-price relationship between oil and carbon dioxide also influence the decision to invest in EOR. Policy interventions that improve the positioning of storage-focused EOR within oil and gas investment portfolios are necessary. Pricing carbon dioxide emissions would provide an important stimulus for CO_2-EOR and would encourage investment in developing new alternative technologies with lower emission profiles or costs. Other options for incentivizing CO_2 storage include investment tax credits, storage credits, tax exemptions on dedicated bonds, master limited partnerships, environmental performance standards, fuel carbon intensity limits and fuel economy standards. Policy instruments such as the EU's fuel directive and the low carbon fuel standard in California have encouraged the increased use of alternative fuels and ensured compliance with declining carbon intensity obligations. The Carbon Offsetting and Reduction Scheme (CORSIA), about to be implemented by the International Civil Aviation Organization, will provide a market mechanism to offset emissions growth from international air transport. CO_2-EOR schemes might be eligible for CORSIA as a compliance mechanism.

Background to the Workshop

CO_2 has been used to recover additional oil from mature reservoirs for decades in the U.S., but the international adoption of CO_2-EOR as a storage option has been minimal. The CO_2-EOR process was initially developed in the 1960s as a means to increase oil recovery. To date, the financial reward that comes from oil production has motivated its implementation. The idea that CO_2-EOR could deliver a material environmental benefit – particularly through CO_2storage – and be rewarded for that benefit is relatively recent. For example, a desire to reduce CO_2 emissions from point sources could create an incentive to capture CO_2 for disposal in geologic formations, such as oil reservoirs and deep saline formations.

While some work has quantified the potential for CO_2-EOR to store CO_2 and increase oil recovery, there has been much less work that has examined the technical approaches to enhance its emissions reduction benefit. A recent IEA Insights Paper analyses the global CO_2 storage potential from EOR and its economics. It concludes that, in certain circumstances, the technology could deliver cost-effective emissions reductions at scale and play a material role in the transition towards decarbonizing economies. Given the unique promise of CO_2-EOR, there is a need for further work to explore the means to enhance the climate benefit of CO_2-EOR and better assess the benefits and constraints of CO_2-EOR on regional scales. Communication between experts from academia and industry with different perspectives is essential for this.

This workshop helped advance research on key issues affecting the development and deployment of CO_2-EOR technologies. Participants discussed the following topics relating to CO_2-EOR:

- The current status of storage.
- Technology and economics.
- Environmental performance.
- Policy frameworks.

Storage – Current Status

CO_2-EOR operations use mature technologies and leverage extensive reservoir engineering capabilities of oil and gas companies. The existing U.S. industry could utilize significantly higher volumes of CO_2 if they were available at affordable prices. Elsewhere, CO_2 is often not available in the volumes demanded by EOR projects. CO_2-EOR operations can securely store CO_2 for centuries. Monitoring, measuring and verification by recognized international standards (e.g., IPCC, ISO) is essential to demonstrate the long-term integrity of storage.

Given that CO_2 utilization rates within EOR fields diminish over time, any contractual requirements for a steady off-take of CO_2 imply that a portfolio of projects – potentially both EOR and saline aquifer storage – needs to be developed to utilize contracted supply capacities effectively. This requirement highlights the importance of pipeline infrastructure to connect multiple sources with a portfolio of EOR projects, as exists in the U.S. today. Given that CO_2 capture represents the largest cost element of a carbon capture and storage (CCS) value chain, it is sensible to start with the CO_2 sources that are cheapest to capture. These include concentrated CO_2 waste streams from hydrogen and ethanol plants, ammonia and urea operations, and natural gas processing, rather than large but low CO_2 concentration emissions sources such as power plants. These concentrated sources currently contribute the bulk of captured CO_2 – approximately 20 million tonnes of CO_2 per year – to the CO_2 supply market in the U.S.

Storage capacity exists both on- and off-shore. However, off-shore storage faces much higher costs, given the smaller number of feasible injection wells and the need for sub-sea separation of oil and CO_2.

Technology and Economics

The effectiveness of CO_2 floods is critically dependent on reservoir miscibility, CO_2 sweep efficiency and the purity of the CO_2 gas used. Various additives and injection techniques can improve the rate of oil recovery from a reservoir and the quantity of CO_2 stored. While the capacity of a given reservoir is fixed by its available pore space, displacing water from the reservoir can increase CO_2 storage volume. Effectively managing produced displaced water can add a significant cost and cause environmental issues for the CO_2-EOR operators if not dealt with adequately and cost-effectively.

While concerns were raised about the integrity of existing infrastructure once CO_2 flooding commences, due to the presence of CO_2 and water, current operators do not have the same degree of concern over pipeline and equipment corrosion and are confident in their ability to manage it.

Because pipeline networks transport large volumes of CO_2 and are currently (and will likely remain) regional, CO_2 prices will vary from system to system. The range and proximity of large emitting industries constrain the volumes of supplied CO_2, their incentive for market participation, and the availability of transportation infrastructure. Markets with a diversity of sources and sinks are more likely to result in efficient and competitive price formation. Fiscal incentives to mitigate carbon influence actual volumes and rates of CO_2 utilized. The availability of large volumes of low-cost saline storage will constrain CO_2 prices.

In emissions trading schemes, the benefits of reducing CO_2 emissions typically accrue to the emitter, usually the company that captures the CO_2. Where CCS is considered an offset generating activity, credits are, likewise, typically awarded to the entity capturing the CO_2. From the standpoint of CO_2 storage, midstream pipeline and EOR operators simply provide commercial services along the CCS value chain. Storage companies also provide monitoring, measuring and verification in line with regulatory requirements. While less frequently discussed, the employment, energy security, and macroeconomic benefits (e.g., tax and trade balance) of CO_2-EOR are important factors to consider.

Environmental Performance

The life cycle of greenhouse gas (GHG) emissions associated with a barrel of oil range from around 400 to 900 kg CO_2eq, and depend on a wide range of factors. These include oil quality, upstream energy consumption, associated natural gas, venting and flaring practices, fugitive emissions, refinery energy demands and distance to market. Opportunities to lower the carbon intensity of oil production exist across the value chain with varying degrees of cost-effectiveness and mitigation potential. While other mitigation options can lower the carbon intensity of oil produced, CO_2-EOR can effectively lower that intensity beyond the plant boundary and through to combustion by end users.

Determining the environmental gain from CO_2-EOR rests on the GHG accounting for each project, utilizing life cycle assessment methodologies to validate the quantity of CO_2 emissions that are permanently avoided. The baseline for comparison and boundaries for project accounting are important parameters. Mitigation performance depends on the carbon footprint of the oil produced and that which it displaces, as well as the carbon footprint of the captured CO_2 supply. To avoid 'double counting' when estimating the carbon intensity of produced oil, the emissions reduction benefits across the entire lifecycle – from CO_2 supply to final fuel use – must be appropriately allocated between oil and other products from the system (e.g., electricity, ethanol, fertilizer).

A number of comments were made regarding the public's lack of understanding, or mistrust, of geological CO_2 storage to reduce emissions. This mistrust relates to wider concerns about advanced CO_2-EOR being used by the petroleum industry to unduly extend fossil fuel use. While these are legitimate concerns, oil and gas will continue to be major contributors to energy supply for decades to come in reference scenarios (e.g., IEA New Policy Scenario) and future energy scenarios consistent with the Paris Accord (e.g., IEA Sustainable Development Scenario). Measures taken today to reduce the carbon intensity of petroleum supply will be beneficial to the climate. This narrative needs to be shaped in language that the intended audience understands. It needs to focus on the societal benefits that advanced CO_2-EOR practices could offer and needs to emphasize both the near-term economic and long-term climate rationales.

Policy Frameworks

The issue of supportive public policy emerged as a point of discussion in each session of the workshop. Greater fiscal and regulatory incentives are needed to begin scaling advanced CO_2 storage through EOR around the globe. A viable and large-scale CO_2-EOR industry depends upon significant capital investments for CO_2 capture and transportation infrastructure. Policy consistency and predictability, combined with targeted subsidies, will help to achieve this goal. Such support will substantially reduce the risks associated with CO_2 pipeline infrastructure development, and allow developers to leverage the economies of scale associated with operating oversized trunk pipelines that would otherwise be unaffordable for individual suppliers or end users of CO_2.

Participants noted that pricing carbon dioxide emissions would provide an important stimulus for CO_2-EOR. The key advantage of pricing emissions is that it provides an ongoing financial incentive for producers and consumers to take cost-effective action to lower emissions. It would also stimulate broader investment in developing alternative technologies that have lower emission profiles or costs. While approximately one-third of global carbon emissions now face some form of carbon pricing, most prices are well below the level required to drive CCS technology or change the behavior in the marketplace (World Bank 2017). Participants also noted that the politics of pricing carbon is often challenging. Participants discussed several other options for incentivizing CO_2 storage, including investment tax credits, storage credits, tax exemptions on dedicated bonds, master limited partnerships, environmental performance standards, fuel carbon intensity limits, and fuel economy standards.

Delegates discussed policy instruments focused on the GHG intensity of fuels, including the EU's fuel quality directive and the low carbon fuel standard in California. To date, the increased use of alternative fuels under these frameworks, such as ethanol, biodiesel, natural gas, electricity and other lower-carbon fuels, rather than investments in advanced CO_2-EOR, has ensured compliance with declining carbon intensity obligations. In principle, the increased use of oil produced from CO_2-EOR could be a compliance mechanism, though the rules of such fuel intensity-based systems may need to be developed to make this a reality.

An additional policy instrument to incentivize decarbonization of transport fuels is the Carbon Offsetting and Reduction Scheme (CORSIA), about to be implemented by the International Civil Aviation Organization. CORSIA will become operative in 2021 on a voluntary basis and will provide a market mechanism to offset emissions growth from international air transport. Details of the offset schemes eligible for CORSIA are evolving and could include advanced CO_2-EOR as a compliance mechanism.

About the Workshop

The workshop took place in Paris from January 30-31, 2018. It brought together some 50 international experts to discuss key issues affecting the development and deployment of CO_2-EOR technologies. It addressed technology and economics, environmental performance and policy drivers.

List of participants

Perumal Arumugam — Programme Officer (Team Lead), Sustainable Development Mechanisms, UNFCCC

Guillaume Batot — Petrophysicist, IFP Energies nouvelles (IFPEN)

Nils-Henrik Bjurstrom — Senior Project Manager, Rystad Energy

Gilles Bourdarot — EOR Project Manager, Total

Steven Bryant — Professor, University of Calgary

Brad Crabtree — Vice President, Fossil Energy, Great Plains Institute

James Craig — Senior Geologist, IEAGHG

David Elzinga — Senior Energy Specialist, Asian Development Bank (ADB)

Mike Godec — Vice President, Advanced Resources International (ARI)

Stephen Goodyear — Manager Gas Flood, Shell

Deborah Gordon — Director, Energy and Climate Program, Carnegie Endowment for Peace

Neeraj Gupta — Senior Research Leader, Battelle

Sveinung Hagen — Leading Researcher — CO_2 Storage and EOR Research & Technology, FVC ES Statoil ASA

Eva Halland — Project Director, Norwegian Petroleum Directorate

Takashi Hongo — Senior Fellow, Mitsui Global Strategic Studies Institute

Jan-Hein Jesse — Consultant, Jesco bv

Anna Korre — Professor of Environmental Engineering, Imperial College

Jia Li — Technical Director, UK-China (Guandong) CCUS Centre

Chris Malins — Consultant, Cerulogy

Sean McCoy — Energy Analyst, Lawrence Livermore National Laboratory (LLNL)

Filip Neele — Project Leader, TNO

Vanessa Nuñez Lopez – Research Scientist Associate, University of Texas at Austin

Bo Peng — China University of Petroleum-Beijing (CUPB)

George Peridas — Senior Scientist, National Resources Defense Council (NRDC)

Charlene Russell — Vice President Commercial Development, Occidental Petroleum

John Scowcroft — Executive Advisor, Global CCS Institute

Hector Silva Gonzalez — National Commission for Fossil Fuels, Mexican Government

Ryozo Tanaka — Senior Researcher, Research Institute of Innovative Technology for the Earth (RITE)

Govinda Timilsina — Senior Economist, Environment and Energy, World Bank

Martin Towns — Senior Portfolio Lead, BP plc

Karen Turner — Centre Director, University of Strathclyde

Jan Paul van Driel — Founder, StrategicFit

Klaas van ‘t Veld — Associate Professor of Economics, University of Wyoming

Ali Vezvaei — President, Bilfinger Middle East

Zhen Wang — Deputy Director-General, Policy Research Office, China National Petroleum Corporation (CNPC)

Peter Wooders — Group Director, International Institute for Sustainable Development (IISD)

Arafat Al Yafei — Research and Development Manager, Abu Dhabi National Oil Company (ADNOC)

Xiaoliang Yang — Research Associate, World Resources Institute (WRI) China

Sonia Yeh — Adlerbertska Visiting Professor, Chalmers University

Paul Zakkour — Director, CarbonCounts

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Thomas Berly — Energy Analyst

Tim Gould — Senior Energy Analyst

Mei Han — Energy Analyst

Juho Lipponen — Head of Unit

Samantha McCulloch — Energy Analyst

Christophe McGlade — Energy Supply Modeler and Analyst

Glenn Sondak — Energy Analyst

Tristan Stanley — Policy and Legal Analyst

Laszlo Varro — Chief Economist

KAPSARC

Robert Arnot — Research Fellow

Doug Cooke — Program Director

Wolfgang Heidug — Senior Fellow

Shahd AlRashed — Research Associate

Colin Ward — Research Fellow

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About the Project

Pathways to Low Carbon Oil is a project that examines the global challenges and opportunities for oil in a carbon constrained world. Mindful of Saudi Arabia's competitiveness in this emerging market, we analyze the existing carbon intensity of upstream operations and the opportunities to reduce that intensity through management strategies and technology, as well as its economic impacts. Understanding the market and player behaviors will provide insights to policy options along with the legal, regulatory and commercial issues that must be addressed. Given Saudi Arabia's place within the wider global economic system, this project has implications for policymakers outside of the Kingdom.

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