

**Demand for Captured CO₂ for Use in Fuels
and Chemicals**

MULTI-CLIENT STUDY PROPOSAL

September 2019



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I. BACKGROUND

The Catalyst Group Resources (TCGR) has been delivering techno-economic assessments on carbon dioxide capture and conversion (CO₂CC) for members of its industrial program with the same name since its inception in 2010. For the first time, TCGR will present a techno-economic evaluation in the field of carbon dioxide utilization available to the general public.

While CO₂ has been used for enhanced oil recovery for some time, its use as a raw material for fuels and chemicals production is still relatively new, with little existing industrial analysis regarding its current and potential market size or technical maturity. Due to the growing impact of CO₂'s role in climate change and the desire to produce durable goods and fuels not based on fossil carbon, increasing amounts of resources are being applied to CO₂ capture and use, as seen by the ever-growing number of start-up companies in this field, as well as the growing number of potential applications for CO₂ being investigated. Organizations such as the Oil and Gas Climate Initiative (OGCI) and the European Commission have dedicated funds to develop CO₂ usage. Clearly, the demand for CO₂ utilization is increasing, and with it comes opportunities in the marketplace, which are certain to have significant impact on the incumbent products and technologies.

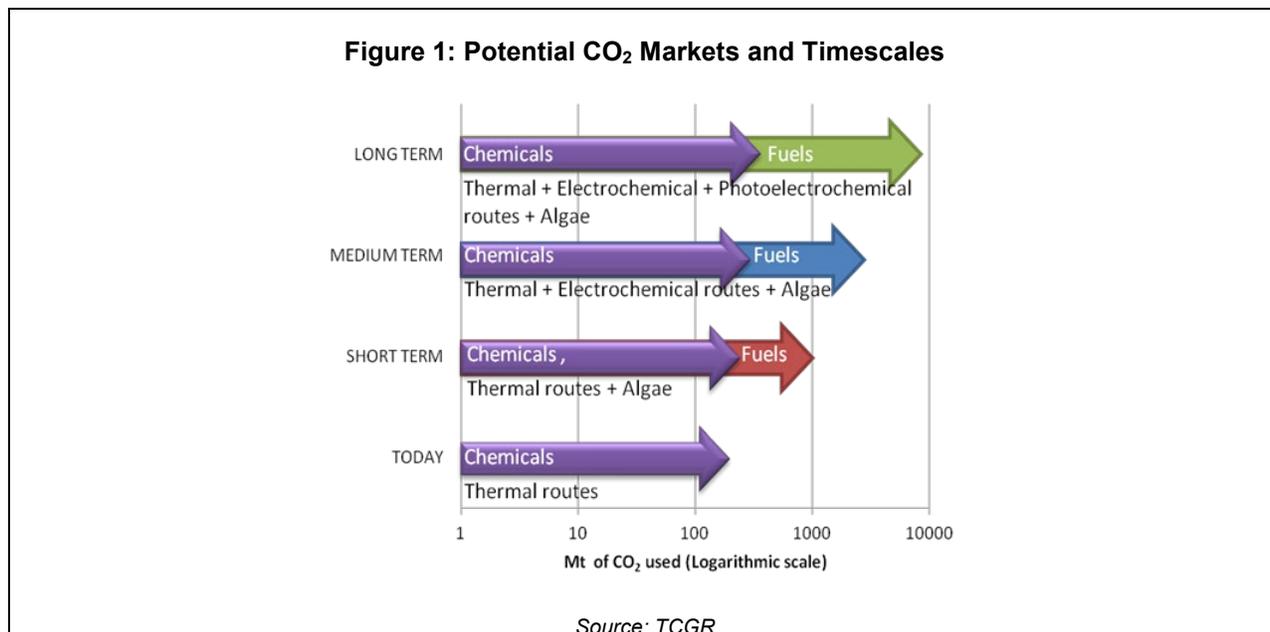
The hallmark of each TCGR multi-client report is “by the industry, for the industry.” This report’s charter subscribers (i.e., those who sign up prior to study launch) will be invited to provide input into the final scope and indicate areas of particular importance to them - whether it be application, technology, process, or market participant - in order to provide the most relevance for our subscribers. TCGR’s reports go beyond statistics to provide competitive insights and analysis vital to stakeholders in the refining, chemicals, petrochemicals and materials markets.

II. INTRODUCTION

Growing concerns about the rise of atmospheric CO₂ and its effect on the climate have led to increased calls for decarbonization and reduction in CO₂ emissions. Until technologies for decarbonization reach maturity, CO₂ capture is looked upon as a significant lever for the reduction of CO₂ emissions (IEAGHG 2017-17, “CCS Deployment in the Context of Regional Developments in Meeting Long-Term Climate Change Objectives”). It is often assumed that captured CO₂ will be sequestered through deep burial, either through an EOR operation or into

a saline aquifer. However, both of those solutions require appropriate geology and infrastructure to handle the large amounts of CO₂ required, and that does not exist in many locations today. In addition, substantial governmental approvals are required to provide permits and address potential liabilities. This raises the question of how to consume other sources of captured CO₂.

The scope of this report is to present the demand for CO₂ that may be used over the next 30 years in both unconverted (e.g., technical fluids like EOR or air conditioning fluids) and converted applications, spanning from fine chemicals, to polymers, to fuels and energy carriers (e.g., methanol). In its groundbreaking 2012 report for members of its **CO₂ Capture and Conversion (CO₂CC) Program** entitled “**Analysis of Demand for CO₂**”, TCGR took a first look at the short-, medium- and long-term supply and demand data for CO₂ and estimated a market demand of just over 1,000 mt for use in chemical compounds in 2020. Since that time, the need for CO₂ capture and conversion has increased, and new technologies have emerged for CO₂ conversion into other products. The importance of life-cycle analysis (LCA) and its impacts on the attractiveness of each conversion route have also grown. This report will update and extend our 2012 study to include LCA and become available to non-members of the **CO₂CC Program** as a multi-client report.



Since the 2012 study, there have been exciting announcements of commercial applications of CO₂ conversion, such as the production of cardyon™ polymers from Covestro, the conversion of CO₂ into methanol, and its incorporation into process routes to hydrogen, syngas, and sulfuric acid by SABIC (Figure 2). Linde is capturing CO₂ from Shell’s Rotterdam refinery and feeding it to local greenhouses, selling to food suppliers to extend shelf life, and sequestering the remainder in underground caverns. BASF has made announcements regarding research activities to make acrylic acid, sodium acrylate and acetone from CO₂, while Evonik is

investigating use of CO₂ to make hexanol and butanol. Furthermore, Linde and BASF have partnered to create a solution for dry reforming of methane, expected to be commercialized in 2020, with further developments in the next few years to convert that syngas to dimethyl ether (DME) and olefins (Figure 3). Longer term outputs from CO₂ utilization could include large-scale algal production of fuels (ExxonMobil) or its use as an air conditioning fluid.

Figure 2: Conversion routes incorporating CO₂ into high-volume chemicals proposed by SABIC

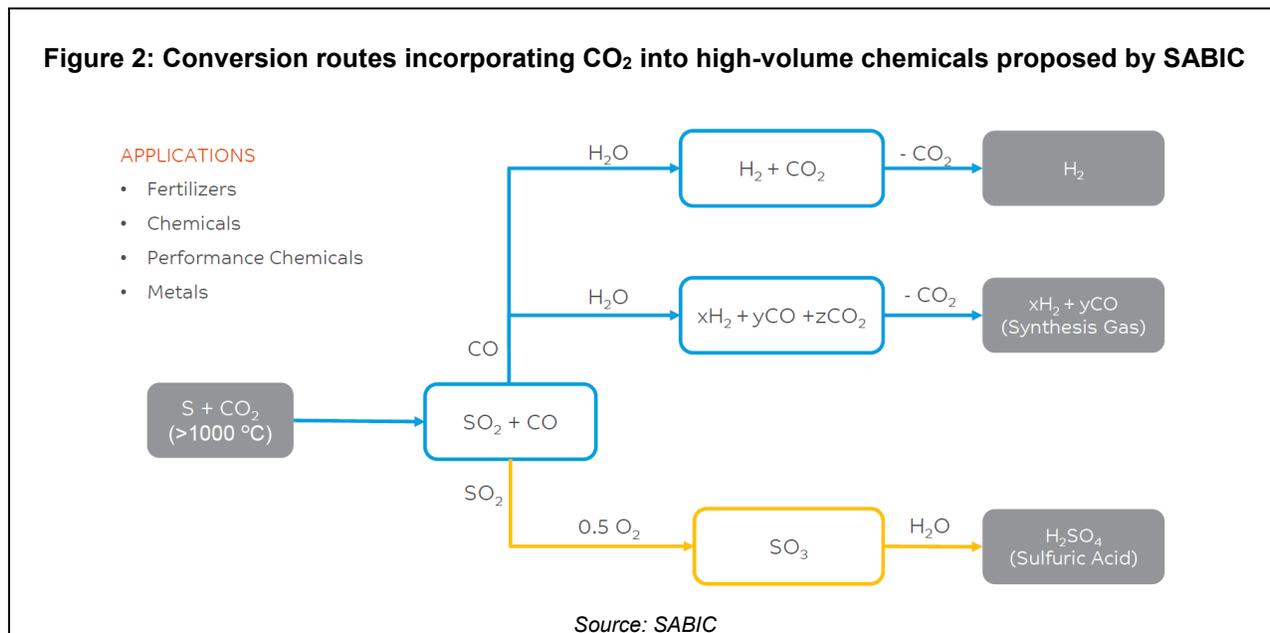
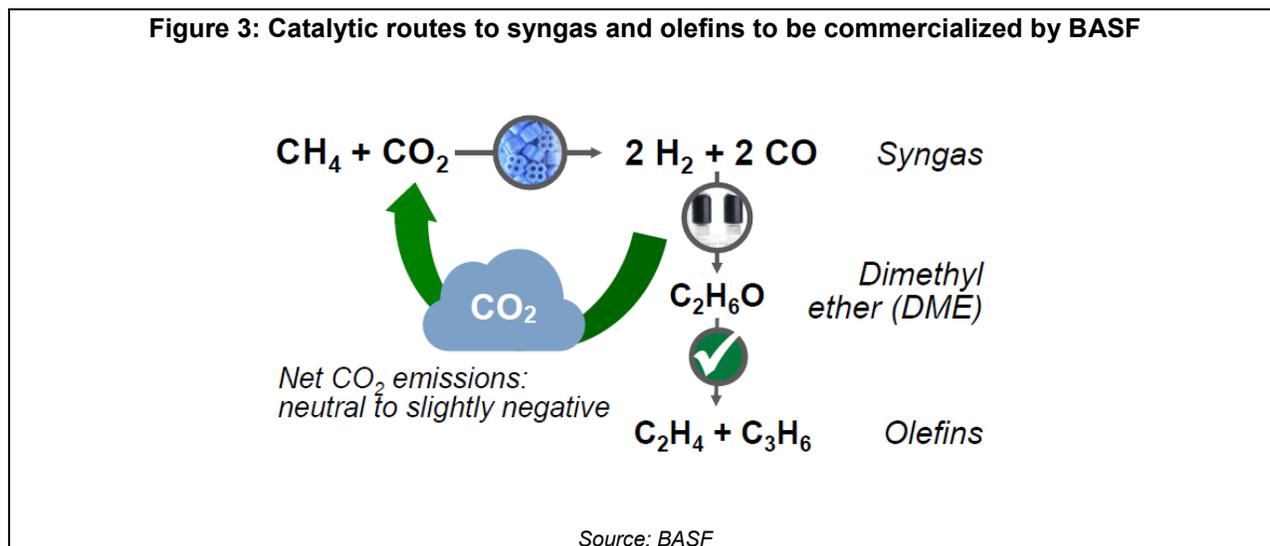


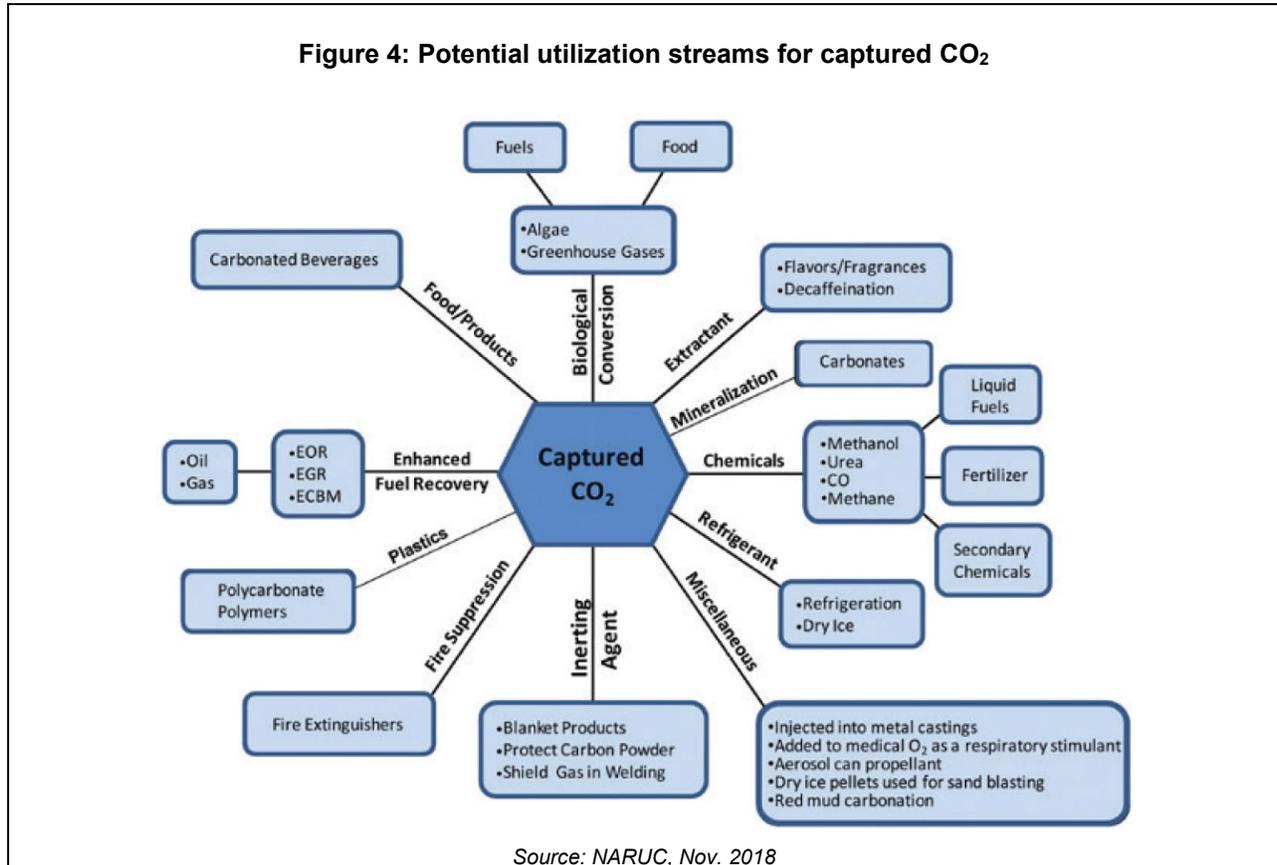
Figure 3: Catalytic routes to syngas and olefins to be commercialized by BASF



Beyond the demand side of the equation, considerable research effort over the past several years has been put into the technologies that enable CO₂ conversion, and this report will present an overview of the state-of-the-art conversion technologies and LCA impacts being proposed by producers, industrial consortia, and government and academic labs across the

globe. This link between technology and markets is a feature of every TCGR multi-client study and will provide insights into this potential market unavailable elsewhere.

Figure 4: Potential utilization streams for captured CO₂



III. THE NEED FOR THE STUDY

Due to increasing environmental and social drivers, the need for such a study has never been timelier. Companies across multiple industries and at various points along the value chain have committed to reductions in CO₂ emissions, but have not yet been able to achieve significant reductions in line with the IPCC 2° scenario. While carbon capture technologies haven't yet achieved the cost scenarios put forth by governmental or international organizations like the IEA and the US DOE, economic incentives like carbon taxes, carbon markets like the European Emission Trading System (ETS), tax credits and low-carbon fuel regulations are creating the economic drivers to increase the adoption of carbon capture as a tool for overall CO₂ reduction. **This study will provide a map of the potential target products and their market size/growth over the next 30 years – with a timeline to commercialization – as well as the challenges to further adoption, driving R&D and engineering efforts to create further efficiencies, reducing costs and ultimately increasing sales.**

Critical topics this study will address include:

- Commercial and potentially commercial products made from CO₂, quantities, and process routes for each, including LCA impacts
- Timelines for commercialization over the next 30 years
- Technology advances, drivers and remaining hurdles
- Key global players in development and commercialization of new technologies
- Regional outlooks based on market opportunities and regulatory drivers
- Strategies for implementation

In our 2012 techno-economic report for **CO₂CC Program** members referenced earlier, TCGR evaluated the potential market demand for CO₂ based on technologies that were mainly still at lab or early stages of development. This study provides a view over the next thirty (30) years and includes additional products and technologies, providing an assessment of volumes, market applications, technologies as well as remaining challenges.

This study also compliments other studies undertaken by The Catalyst Group Resources, demonstrating TCGR's unique capability and resources to deliver exceptional insight. Recent techno-economic reports produced for member clients of the **CO₂CC Program** include "***State of the Art and Future Prospects for Electrochemical CO₂ Conversion***", "***CO₂ Utilization in Reforming***", "***Progress Towards Technologically and Commercially Viable CO₂ Conversion to Olefins, Acids and Esters***", and "***System Perspectives/Net GHG Benefit of CO₂ Conversion Technologies***."

IV. SCOPE AND METHODOLOGY

TCGR's study will assess recent technology developments for the use of CO₂ as a raw material and provide a comprehensive look at the market potential for the various outlets for captured CO₂ with the goal to provide insightful, timely advice in both technical and commercial directions.

Topics included are:

- Existing and developing technologies for the use of CO₂, with LCA impacts
- Existing and potential demand for CO₂
- Supplier profiles and commercial partnerships
- Strategic analyses and competitive implications

This report will have three sections organized around the short (<5 years), medium (5-15 years), and long-term (15-30 years) market opportunities for CO₂ use. Each of these sections will detail the existing or potential market opportunities, technology status and hurdles, and commercial implications of the relative state of the technology.

A key component of these individual analyses will be a techno-economic evaluation and LCA impacts of the underlying technology. Each of these sections will detail the companies (both new and established) and technologies in the CO₂-use value chain, their opportunities, and any obstacles to market acceptance.

All TCGR multi-client studies are characterized by competitive and strategic insights for industrial and financial companies to evaluate. These include key trends, concerns, and conclusions on the best return on investment (ROI) actions, competitive expectations, and strategic SWOT's on the players. TCGR is noted for its sound strategic advice in over 35 years of experience.

TCGR's unique background and established global Dialog Group® ensures expert capability and skill level in this study area. TCGR will utilize numerous deeply experienced experts in CO₂ capture and conversion as well as chemicals, fuels and materials (e.g., polymers) production to assist us in providing insights beyond what other sources that do not have comparable reach and industrial experience can provide.

As it does in each of its industrially-focused multi-client studies, TCGR will seek input from “charter” subscribers (i.e., those who sign-up prior to study launch) to help shape the report's final scope and table of Contents. This interactive and client-driven methodology ensures that the final report covers and emphasizes the most pertinent content due to the numerous process approaches covering a range of inputs and end-products that might be of interest.

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V. QUALIFICATIONS

The Catalyst Group Resources, a member of The Catalyst Group, works with clients to develop sustainable competitive advantage in technology-driven industries such as chemicals, refining, petrochemicals, polymers, specialty/fine chemicals, biotechnology, pharmaceuticals, and environmental protection. We provide concrete proven solutions based on our understanding of how technology impacts business.

Using our in-depth knowledge of molecular structures, process systems, and commercial applications, we offer a unique combination of business solutions and technology skills through a range of client-focused services. Often working as a member of our clients' planning teams, we combine our knowledge of cutting-edge technology with commercial expertise to:

- Define the business and commercial impacts of leading-edge technologies
- Develop technology strategies that support business objectives.
- Assess technology options through strategy development, including:
 - Independent appraisals and valuations of technology/potential
 - Acquisition consulting, planning and due diligence
- Provide leading-edge financial methodology for shareholder value creation
- Lead and/or manage client-sponsored R&D programs targeted through our opportunity identification process.
- Provide leading information and knowledge through:
 - World-class seminars, conferences and courses
 - Timely technical publications

The client-confidential assignments conducted by The Catalyst Group include projects in:

- Reinventing R&D pipelines
- Technology alliances
- Technology acquisition
- Market strategy

We have built our consulting practice on long-term client relationships, dedication, and integrity. Our philosophy is clear and focused:

***We Provide the "Catalysts" for Business Growth by Linking Technology
and Leading-Edge Business Practices to Market Opportunities***

VI. DELIVERABLES AND PRICING

This report is timely and strategically important to those industry participants and observers considering investment, as well as to technology companies evaluating CO₂ use and conversion markets. TCGR's report, based on technology evaluations, market assessments and interviews with key players goes beyond public domain information. As a result, subscribers are requested to complete and sign the "Order Form and Secrecy Agreement" on the following page.

"Demand for Captured CO₂ for Use in Fuels and Chemicals" will be available in February 2020.

<u>Participation</u>	<u>Deadline</u>	<u>Price</u>
"Charter" subscribers*	before October 11, 2019	US\$20,500
Post-launch subscribers	after October 11, 2019	US\$23,000
Report in PDF format, in addition to subscription price		US\$1,000

**Charter subscribers (those who sign up for the study before October 11, 2019) will have the opportunity to work with TCGR in defining the scope of the report by delineating areas of particular interest for inclusion in the assessment.*

* * * * *

Due to the complementary nature of this study to TCGR's **Carbon Dioxide Capture & Conversion (CO₂CC) Program** techno-economic report entitled ***"Analysis of Demand for CO₂"*** (completed in 2012 exclusively for members), TCGR is offering a discount of \$1,000 off ***"Demand for Captured CO₂ for Use in Fuels and Chemicals"*** to members who elected to receive that study. Additional information, including the complete study proposal, the preliminary Table of Contents and the Order Form, is available at: http://www.catalystgrp.com/multiclient_studies/demand-for-captured-co2-for-use-in-fuels-and-chemicals/ or by contacting Steve Deutsch at +1.215.628.4447 or sdeutsch@catalystgrp.com.

The Catalyst Group Resources (TCGR), a member of The Catalyst Group, is dedicated to monitoring and analyzing technical and commercial developments in catalysis as they apply to the global refining, petrochemical, fine/specialty chemical, pharmaceutical, polymer/elastomer and environmental industries.

ORDER FORM AND SECRECY AGREEMENT

The Catalyst Group Resources, Inc. Tel: +1.215.628.4447
 Gwynedd Office Park Fax: +1.215.628.2267
 P.O. Box 680 e-mail: tcgr@catalystgrp.com
 Spring House, PA 19477 - USA - website: www.catalystgrp.com

Please enter our order for **“Demand for Captured CO₂ for Use in Fuels and Chemicals”** to be completed February 2020, as follows:

- _____ **“Demand for Captured CO₂ for Use in Fuels and Chemicals”** as a “charter” subscriber (i.e., prior to October 11, 2019) for \$20,500 (\$23,000 after study launch).
- _____ Please enter our order for the study to be delivered in PDF (Adobe Acrobat) format for use across our sites/locations (i.e., site license) for an additional \$1,000.
- _____ Please send us _____ additional printed copies @ \$250 each.
- _____ We are members of TCGR’s **Carbon Dioxide Capture & Conversion (CO₂CC) Program** and received the 2012 techno-economic report entitled **“Analysis of Demand for CO₂”** and are therefore entitled to the \$1,000 discount off the subscription price.

In signing this order form, our company agrees to hold this report confidential and not make it available to subsidiaries unless a controlling interest (>50%) exists.

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