

*Thought Leadership > Competitive Benchmarking > Technology-driven Business Strategies*



*Depth of Knowledge > Technical & Commercial Developments > Strategic Reassessments*

# **THE SEPARATIONS REPORT – 2021: Commercial, Technical and R&D Assessment in Refining, Petrochemicals/Syngas, Natural Gas and Industrial Gases**

**– Third Biennial Edition –**

**UPDATED MULTI-CLIENT STUDY PROPOSAL**

**June 2021**

# THE SEPARATIONS REPORT – 2021: Commercial, Technical and R&D Assessment in Refining, Petrochemicals/Syngas, Natural Gas and Industrial Gases

– Third Biennial Edition –

## I. BACKGROUND & INTRODUCTION

In 2017, The Catalyst Group Resources (TCGR) delivered to subscribers the inaugural edition of its biennial multi-client report series entitled “**THE SEPARATIONS REPORT: Commercial, Technical and R&D Assessment in Refining, Petrochemical/Syngas, Natural Gas and Industrial Gases.**” The report was the first of its kind to provide comprehensive global data on market size (volumes and values), growth rates and competitor profiles, for applications across the separations industries. That report, as well as the subsequent Second Edition in 2019, also highlighted the use and advances of separations technologies in emerging and rapidly growing applications like hydrogen production, carbon capture, natural gas purification, and biofuels as well as the decarbonization benefits found through process intensification and new technologies like membrane separations of olefins and paraffins.

Competitive offerings (by separation approach, including membranes, adsorbents, reactive separations, distillation, and integrated approaches, etc.) were provided so that industrial participants in commercial development, technology development and competitive/strategic planning could find market opportunities for further pursuit. Critical to the report’s value was its unique scope and methodology: ***The Separations Report* series focuses exclusively on industrial process streams and waste streams, anticipating the market trends and societal forces impacting industry over the next five to ten years. Evaluations of technology changes and their impacts on commercial offerings permit forecasts of penetration by new approaches and side-by-side comparisons between them, including remaining hurdles. The series is “by the industry, for the industry,” and unlike anything available from other sources.**

TCGR is pleased to return to this subject area in 2021 and offer this updated, refined and further expanded industrial evaluation of separations. Building on earlier editions, **this edition will comment further on areas of particular importance or rapid change such as the hydrogen economy, industry decarbonization, carbon circularity, product sustainability and climate change**, while continuing to highlight technical advances which are certain to change the competitive landscape. As ever, TCGR will offer the opportunity for “charter” subscribers (i.e., those who sign-up prior to study launch) to provide input into the final scope and indicate areas of particular interest or importance to them – whether it is a market/application, an approach (membrane, adsorbent, etc.), a stream/process or a participant/competitor.

Following in the footsteps of ***The Intelligence Report***, TCGR’s biennial catalyst industry study that’s been in production for 36 years, this new biennial report series, ***The Separations Report*** will be a new “gold standard” for the separations industry. TCGR is creating the definitive resource for information about the market size and growth for separation and purification within industrial processes.

**The Separations Report will go beyond statistics to provide competitive insight and analysis vital to stakeholders in the refining, petrochemicals/syngas, natural gas and industrial gases markets while also providing strategic guidance for innovation, growth and investment opportunities across the entire value chain.**

## II. HIGHLIGHTS

All separation processes, whether they be distillation, extraction, adsorption, membrane and/or hybrids (including reactive separations), are becoming more sophisticated on an application by application basis. In the past, both commercially and scientifically (from an R&D perspective), each one has been treated as a somewhat independent chemical engineering discipline, so that choosing the best separation approach for a given application was always a complex but sometimes daunting task, involving both chemical and engineering economic challenges. There is a need to bring these divergent issues together into a more rational commercial understanding and to develop comparative systems, so in the future making these choices will be easier. **The drivers/incentives for this effort are, of course economics, but also macroeconomic ones like regulation (tighter product specifications), the drive toward energy efficiency and ESG pressures like decarbonization, circularity, sustainability, and 2050 Net Zero objectives.**

A snapshot of the progress in technological and commercial developments in just the past two years reflects an ongoing commitment to gains along with a strong interest from industry to consider and evaluate the offerings. The following developments in each approach justify more careful consideration for documentation in TCGR's proposed study.

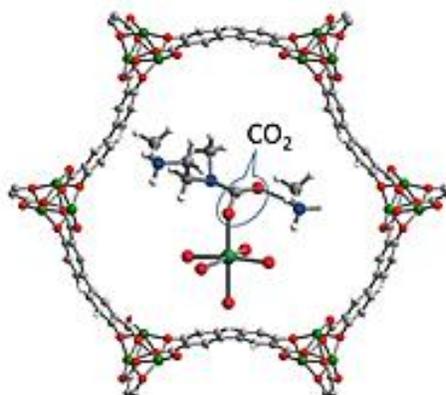
### Adsorbents

Natural materials (e.g., clay, activated carbon, silica, etc.) once dominated the adsorption field, but now engineered materials such as zeolite molecular sieves (ZMS), modified aluminas and metal oxides have gained significant market share, especially in applications that benefit from increased performance. New materials like MOFs, COFs and ZIFs are finding increased attention. The value provided by these advanced engineered adsorbents justify a premium and warrant this timely update on the new developments within the technologies and markets.

- Ingevity has partnered with **natural gas** equipment provider Ozinga Energy to use its Nuchar™ Fuelsorb™ carbon-based adsorbents in a line of natural gas-fuel vehicles. The use of adsorbed natural gas reduces the pressure of the stored gas and allows for a 50% increase in the volume of stored gas (Ingevity, 2020).
- Well established **Biogas upgrading**, via adsorptive separation, continues to advance. Xebec is testing a composite sorbent technology developed by Lawrence Livermore National Lab based on silicone and a carbonate composite material that reacts with CO<sub>2</sub> in the presence of water to remove CO<sub>2</sub> from biogas. (Lawrence Livermore National Lab., 2019).

- The high level of **natural gas** production prior to the pandemic provided incentive for developments in natural gas purification and separation. BASF launched Durasorb™ HG, a mixed metal oxide containing a promoted copper sulfide phase for mercury removal from natural gas and Durasorb HRU for removal of BTX components from liquified natural gas. Durasorb Cryo-HRU has been qualified by Shell for use in LNG production plants (*Hydrocarbon Engineering*, 2020).
- **Climate change** continues to be a driver for technical development. ExxonMobil and Mosaic Materials have partnered to use Mosaic's MOFs to separate carbon dioxide from air or flue gas (*Green Car Congress*, 2020).

**Figure 1. MOF for Carbon Capture**



*MOF pore structure; the inset shows captured CO<sub>2</sub>. Atom colors: oxygen (red), carbon (gray), nitrogen (blue), magnesium (green). Source: ARPA-E.*

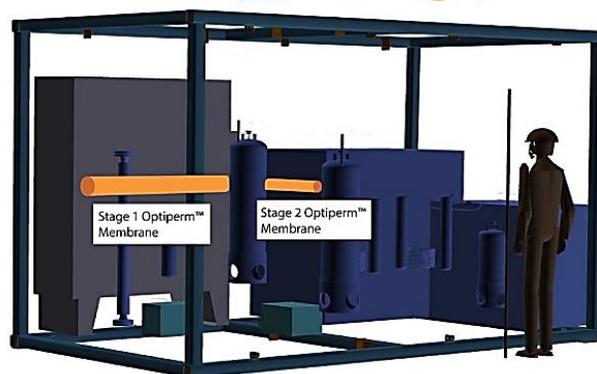
## Membranes

The search for competitive advantage in the application of membranes continues unabated. Advances in design and manufacturing techniques combined with the energy-saving potential of membranes has progressed to the point that membrane-based separations are an established reality in selected applications and becoming increasingly viable in other applications. Indeed, membranes have begun to replace adsorbents and thermal separations processes, with some membranes even creating new revenue streams (e.g., the recovery of olefins from purge streams that have traditionally been unprofitable using thermal separation). In addition, membranes have been successfully used to recover hydrogen from refinery applications. Performance gains against the incumbent technologies are difficult to ignore, as depicted in the following advances:

- The **separation of olefins** using membranes continues to attract a great deal of attention. Recently, Braskem and Compact Membrane Systems announced a pilot program for the use of CMS's Optiper™ membranes for the separation of olefins at a Braskem site. The pilot plant is expected to open in the first quarter of 2021 and be in operation for 500 days (CMS, 2021).

Figure 2. Pilot System for Olefin-Paraffin Separation

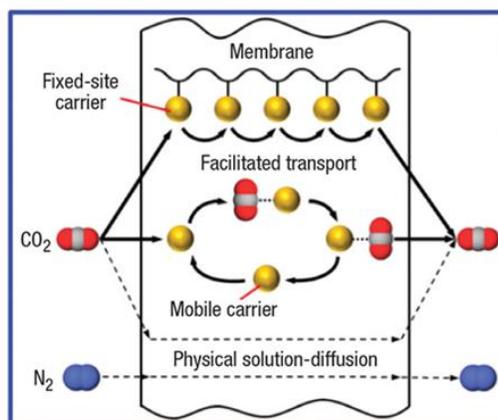
Braskem & Compact Membrane Systems



*Elevation drawing of the complete 2-stage Optiperm™ membrane skid to be installed at Braskem. Membrane stages (orange) are labeled and balance of equipment (blue) is shown to scale. Source: CMS, 2021*

- In the area of **natural gas separation**, Evonik and Linde have announced a partnership for the marketing of Evonik's Sepuran® membranes under Linde's "HISELECT powered by Evonik" name. This hollow fiber membrane technology is suitable for natural gas streams containing high levels of CO<sub>2</sub>, while remaining robust to other natural gas components. Methane losses through the membranes are estimated at 1-4%, which can be further reduced through the application of a second membrane stage (Linde Engineering, 2020). wherein the silver acts as a facilitating agent to allow the olefin to cross the polymeric membrane.
- An important new development was announced in 2020 by ExxonMobil, working in collaboration with Imperial College and Georgia Tech. The collaboration produced a membrane which is capable of **separating crude oil** and crude-oil fractions, offering the potential to help decarbonize oil refining. A novel N-Aryl-linked spirocyclic polymer was developed and applied to a robust substrate in order to separate a complex mixture of hydrocarbons without the application of heat. The researchers have reported the recovery of gasoline and jet fuel fractions from crude, with a molecular weight cutoff of 253 daltons, compared to existing membranes which have a cutoff closer to 600 daltons (Georgia Tech, 2020).
- In the area of **CO<sub>2</sub> capture**, Gas Technology Institute (GTI) will scale up a new hollow-fiber membrane technology for testing of CO<sub>2</sub> removal from flue gas at the Wyoming Integrated Test Center. The CO<sub>2</sub>-selective membrane was developed at Ohio State University and works by a facilitated transport mechanism using amino groups in the membrane. Other flue gas components are transported slower through the membrane, effectively separating the CO<sub>2</sub>. The team has a goal of 95% CO<sub>2</sub> purity and a cost of \$30 per ton of CO<sub>2</sub> captured (Chemical Engineering, 2021).

**Figure 3. Schematic of Facilitated Transport Membrane for CO<sub>2</sub> Capture Developed by Ohio State University**



Source: *Chemical Engineering*, 2021

### Reactive Separations and Process Intensification

- The University of Minnesota (USA) has reported on novel metal halide absorbents for the separation of **ammonia and hydrogen** exiting a reactor. These absorbents, based on magnesium chloride, can be used in a cyclic operation to replace a condenser, thus improving the energy efficiency of the process (*Applied Energy Materials*, 2020)
- Cyclic distillation has seen limited use in the petrochemical industry but has begun to be used for the separation of ethanol for **biofuels, industrial solvents distillation, and fractionation of kerosene**. Cyclic distillation derives its benefits from an increase in the driving force for separation through a modification of the column operating principle with the use of modified internals. These benefits include lower energy requirements (by up to 35%), reduced capital costs, and better column performance (*Hydrocarbon Processing*, 2021).

**Figure 4. Trays for Cyclic Distillation Operation**



Trays suited with sluice chambers, especially designed for cyclic distillation columns (left). Top view of an installed cyclic distillation tray column with a diameter of 1.7 m (right). Source: *Hydrocarbon Processing*, 2021

### III. THE NEED FOR THE STUDY

As 2021 begins, a new environment caused by the global Covid-19 pandemic and the subsequent reduction in travel and many common business activities, has resulted in short-term disruptions to the oil, natural gas, and some downstream chemicals markets, while work on developing markets like carbon capture and green hydrogen production continue with little slow-down. The short-term impacts of the pandemic are becoming clearer, but the implications over the next 5-10 years are still hazy. The third edition of *The Separations Report* will bring together an assessment of technologies, suppliers, and markets like no other, with the goal of shedding light on the future of materials and markets for separation science.

It is clear from the past two editions of *The Separations Report* that the impacts of new technologies have wide impact:

- Membranes enabling zero-liquid discharge and reduced energy consumption impact corporate sustainability goals and decarbonization
- As demand for hydrogen grows due to increased needs for refining as well as a clean energy source, membranes and hybrid approaches improve the economics of H<sub>2</sub> production, enabling the energy transition
- Organic solvent nanofiltration and membrane bioreactors are becoming economically viable for large-scale biochemical production, helping to advance carbon circularity
- Many different membrane technologies are being tested for carbon capture and sequestration towards industry decarbonization
- Adsorbents have been shown to be useful for propane/propylene separation, reducing both cost and carbon dioxide emissions
- The economics and emissions profiles of methanol and ammonia syntheses have been improved through the use of adsorptive separation schemes for purification of the products
- New zeolites are improving the performance of industrial gas separations nearly equivalent to cryogenic separation, improving energy efficiency of the processes
- Novel sorbents and processes are being developed and deployed for Direct Air Capture (DAC) of carbon dioxide

These advances from the past few years are seeing further development today and they will begin to displace incumbent technologies over the next few years. Our clients have made it clear that **there is industry interest in a regularly scheduled update focusing on all aspects of separations and purification so as to capture the developments in a rapidly changing world.**

**Capturing the breadth of developments across separations applications and types, in one place, allows for comparisons and assessments in which incumbent vs. new can be made, providing value to subscribers.**

This 2021 edition of *The Separations Report* is needed to update the 2019 report's review of new technologies and developments more deeply, in order to provide separations users with the knowledge necessary to make important decisions about how to improve their operations across the breadth of applications. Separations producers will also find the market size/growth and industry participants analysis important for their competitive intelligence, providing guidance on the fastest growing markets/applications to enter.

This study compliments an ongoing portfolio of similarly well received studies The Catalyst Group Resources has delivered to clients over recent years. This growing experience demonstrates TCGR's unique capability, resources and expertise to deliver exceptional insight. Recent multi-client studies, limited-client studies and reports from TCGR's membership programs, notably the **Catalytic Advances Program (CAP)** and the **Carbon Dioxide Capture and Conversion (CO<sub>2</sub>CC) Program**, include:

- ***The Intelligence Report: Business Shifts in the Global Catalytic Process Industries, 2019-2025*** (May 2020)
- ***Advances in Direct Air Capture of CO<sub>2</sub>*** (December 2019)
- ***Compact Light-Weight CO<sub>2</sub> Capture Technologies for Small- to Medium-Scale CO<sub>2</sub> Emitters*** (September 2019)
- ***Recent Progress in Zeolitic Membranes for Gas Separations and Catalysis*** (December 2016)
- ***Benchmarking CO<sub>2</sub> Capture Technology (Vol. 3): Update on Selected Pre-/Oxy-Combustion and Post-Combustion Capture Routes*** (September 2016)

#### **IV. SCOPE AND METHODOLOGY**

TCGR's study will document and assess, on both scientific and techno-economic bases, recent developments in separation technologies and compare them to current industrial state-of-the-art alternatives with the objective of providing insightful, timely advice in both R&D/ technical and commercial directions.

Topics included are:

- Market size/growth
- Application advances by industry
- Technical advances by separations approach (i.e., adsorbents, membranes, distillation/thermal, reactive separations, etc.)
- Implications on key drivers, including energy transition, decarbonization and carbon circularity
- Strategic analysis and competitive implications

As depicted in the Preliminary Table of Contents (see pages 9-10), TCGR's study begins by completing an overview of the market size and growth for separations by application (**Section III**).

**Section IV.** Advances in Separations Applications, documents new products and processes that have recently debuted and the progress towards commercialization for various applications. *It is in this section that TCGR anticipates its "charter" subscribers (i.e., those who sign up prior to study launch) will provide input/guidance regarding the applications, by industry and separations method, of greatest interest to them.*

**Section V.** Technical Advances in Separations, documents R&D and technical trends through expert review and analysis of recent trade literature and conference proceedings as well as pertinent patent analyses. An outlook on which changes might be expected in the market from technical advances beyond the status quo is highlighted.

**Section VI.** Competitive and Commercial Impacts, provides an insightful analysis on the future impact of new technologies and applications. The potential timeline and extent of replacement will be analyzed to understand implications on incumbent technologies and suppliers.

**Section VII.** Strategic Analysis and Business Recommendations, provides TCGR's strategic guidance on opportunities as a result of competitive/commercial shifts.

All TCGR studies are characterized by competitive and strategic insights for industrial and financial investment 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 nearly 40 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 membranes and separations to assist us to provide insights beyond what other sources that do not have the 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 to help shape the report's final scope/TofC so that it covers and emphasizes the most pertinent content due to the large volume of research and the numerous separations approaches (e.g., ab/adsorbent, membrane, reactive separation, etc.) and application areas that might be of interest.*

## Preliminary Table of Contents \*

# THE SEPARATIONS REPORT - 2021: Commercial, Technical and R&D Assessment in Refining, Petrochemicals/Syngas, Natural Gas and Industrial Gases

– 3<sup>rd</sup> Biennial Edition

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### SECTION II. EXECUTIVE SUMMARY

### SECTION III. GLOBAL SEPARATIONS MARKET SIZE AND GROWTH, BY APPLICATION

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3. Industrial Gases
4. Natural Gas
5. CO<sub>2</sub> Capture
6. Other

#### B. ADSORBENTS

1. Refining
2. Petrochemicals/Chemicals/Syngas
3. Industrial Gases
4. Natural Gas
5. CO<sub>2</sub> Capture
6. Other

#### C. OTHER (e.g., REACTIVE SEPARATIONS, DISTILLATION, ETC.)

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### E. STRATEGIES FOR GROWTH AND IMPLEMENTATION

*\*Charter subscribers (those who sign up for the study prior to launch) will have the opportunity to work with TCGR to further refine the scope of the report by delineating areas of particular interest, including the applications by industry and case studies, as depicted in Sections IV and V in the ToC above.*

## 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 both monitoring and investing in the development and implementation of new technology in separations for application in the refining, petrochemicals/syngas, natural gas and industrial gases industries. TCGR's report, based on technology evaluations, commercial/market assessments and interviews with key players will go beyond public domain information. As a result, subscribers are requested to complete and sign the "Order Form and Secrecy Agreement" on the following page.

The study, "**THE SEPARATIONS REPORT - 2021: Commercial, Technical and R&D Assessment in Refining, Petrochemical/Syngas, Natural Gas and Industrial Gases (3<sup>rd</sup> biennial edition)**" is expected to be available within 3-4 months of study launch.

<u>Participation</u>	<u>Deadline</u>	<u>Price</u>
<u>"Charter" subscribers*</u>	<u>prior to launch</u>	\$21,500
<u>Post-launch subscribers</u>	<u>after launch</u>	\$24,000
Report in PDF format, in addition to subscription price		\$1,000

*\*Charter subscribers (those who sign up for the study prior to launch) will have the opportunity to work with TCGR to further refine the scope of the report by delineating areas of particular interest for inclusion in the assessment.*

\* \* \* \* \*

### **Notice to Subscribers of TCGR's 2017 and/or 2019 editions of *The Separations Report*:**

*Due to the complementary nature of this study to TCGR's previous reports in this area, **THE SEPARATIONS REPORT – 2019 (2<sup>nd</sup> edition)** and **THE SEPARATIONS REPORT – 2017 (1<sup>st</sup> edition)**, TCGR is offering a discount of \$1,000 off **THE SEPARATIONS REPORT – 2021 (3<sup>rd</sup> edition)** to subscribers of either of those reports. Subscribers are requested to contact Steve Deutsch at +1.215.628.4447, or [sdeutsch@catalystgrp.com](mailto:sdeutsch@catalystgrp.com) if further details are required or to determine if your organization is entitled. When completing the order form, please make sure to indicate your company's subscription to the earlier report(s).*

## ORDER FORM AND SECRECY AGREEMENT

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