THE SEPARATIONS REPORT: COMMERCIAL, TECHNICAL AND R&D ASSESSMENT IN REFINING, PETROCHEMICALS/ SYNGAS, NATURAL GAS AND INDUSTRIAL GASES

STUDY PRESENTATION

(STUDY COMPLETED OCTOBER 2017)

October 2017

TCGR THE CATALYST GROUP RESOURCES™

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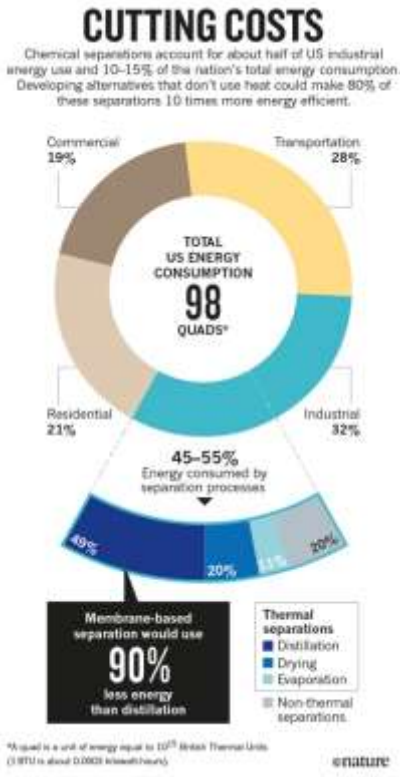
STUDY COMPLETED!

This TCGR assessment was completed in October 2017. The study's scope, and specific contents (as depicted in the TofC on pages 9-22), reflect the inputs from a group of "charter" subscribers who indicated their priorities for coverage, areas to be expanded/deepened and focal points for emphasis in opportunity identification. These are leading industrial developers, suppliers and end users in separations technologies, including membranes, adsorbents, distillation and other approaches (e.g., liquid/liquid).

I. Introduction

Traditional separations and purification processes have relied on thermal technologies such as distillation and physical/chemical adsorption. The phase-change transformations in distillation and the constant pressurization/depressurization cycles of adsorption require significant energy input. With this in mind, it's no surprise that the chemicals separations processes commonly employed today reportedly account for about half of U.S. industrial energy use and 10-15% of the U.S.'s total energy consumption (see **Figure 1**). This large energy usage and monetary cost is driving the need to develop more energy efficient separations technology. As an added incentive, the potential for global carbon taxes will further increase the need to reduce the reliance on energy-intensive separations processes.

Figure 1



Source: Nature, Volume 532, pp 435

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Developments towards more efficient adsorbents and adsorption processes are the goal of many technology providers and new membrane based processes that don't require thermal or physical (pressure) energy to separate components have become a focus, too. As separations as a whole shifts from the thermal based distillation processes to rely more on adsorbents/membranes, it's important to document the advances in technology, the new market opportunities and competitive opportunities/threats that arise.

Following in the footsteps of **The Intelligence Report**, The Catalyst Group Resources' (TCGR's) biennial catalyst industry study that's been in production for 32 years, TCGR's new biennial report series, **The Separations Report** represents a new "gold standard" for the separations industry. TCGR has created the definitive resource for information about the market size and growth for separation and purification within industrial processes. Key focus is paid to which incumbent technologies are at risk of replacement due to cost, integration, etc. and the advances in technology that are driving the change/growth. **The Separations Report goes 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. BACKGROUND

Most of the excitement in the processing industries is a result of new catalyst and production processes that provide novel routes to familiar products and new products that replace those traditionally used. Even marginal improvements to activity rates and yields provide benefits to production margins. While the reaction section garners most of the attention, it's easy to forget that separation and purification is of paramount importance within the processing industries. **The importance of separations will only become greater as more advanced and specialized processes/products are developed.**

Both (1) adsorbents and (2) membranes are critical to the separation and purification of hydrocarbons and industrial gases. More stringent standards for product purity and contaminants along with a new emphasis on energy efficiency are making separations media and improved processes a focus for both producers and end-users.

- **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 (see **Figure 2**). New materials like MOFs, COFs and ZIFs are finding increased attention. The value-added provided by these advanced engineered adsorbents justify a premium and warrant TCGR providing an update on the new developments within the technology and market.

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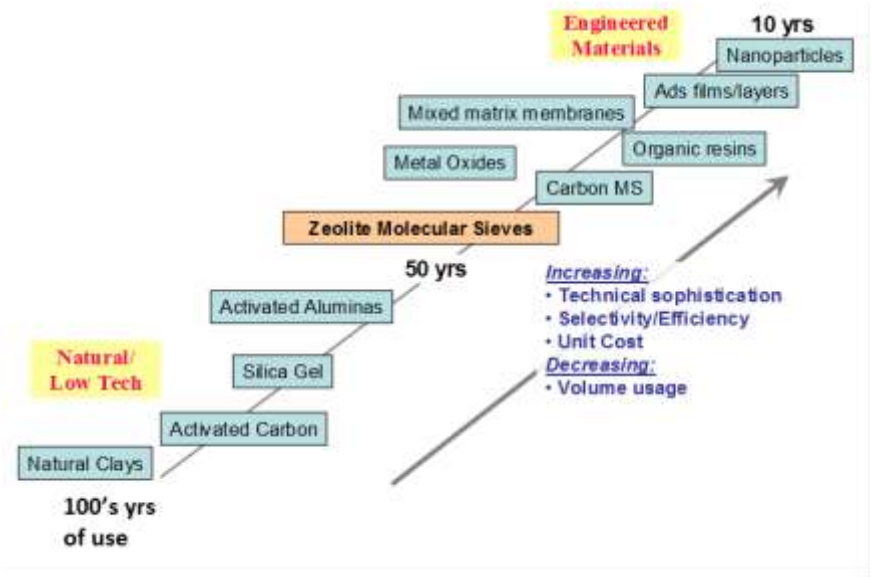
Figure 2
Porous Materials Used as Adsorbents Over the Years

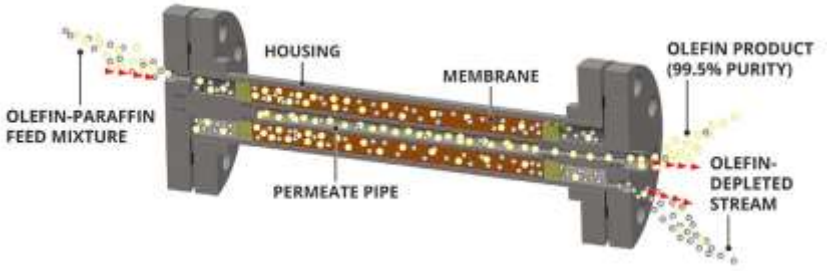


Source: ***The Industrial Adsorbents Business: Commercial Strategy, Technical and R&D Assessment in Refining, Chemicals/Syngas, Natural Gas and Industrial Gases*** (July, 2013), TCGR.

- **Membranes**

  The search for competitive advantage has continued in the application of membranes. Advances in design and manufacturing techniques of membranes have progressed to the point that membrane-based olefin/paraffin separation is a reality. Two companies of note, IMTEX and Compact Membrane Systems, have developed equally impressive systems for olefin/paraffin separation that are currently being tested on a pilot scale or will be tested in the near future (see **Figure 3**). These trials wouldn't have been possible just 5 years ago. Indeed membranes have begun to replace adsorbents and thermal separations processes. These membranes are even creating new revenue streams such as the recovery of olefins from purge streams that have traditionally been unprofitable using thermal separation. As olefin/paraffin separation membranes gain market share, it's important to track the development, implementation and implications of their use.

Figure 3
Cross-Sectional View of a Permylene Membrane Module



Source: IMTEX website (www.imtexmembranes.com)

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Separately, membranes have also been successfully used to recover hydrogen from refiner applications. Several examples exist such as Air Liquide's MEDAL™ and MTR's VaporSep-H_2™ membranes. The benefit of this application comes from the energy savings provided by operating as significantly lower temperature than conventional process. This application is real and will continue to increase in popularity. Performance gains against the incumbent technology make this application difficult to ignore!

III. THE NEED FOR THE STUDY

TCGR has recently completed dedicated studies in both the areas of adsorbents and membranes. These are the first studies we've done in the respective areas in over 10 years:

- ***Membranes in Separations: Commercial Advances in Refinery, Petrochemical/ Chemical and Industrial Gases Applications*** (November, 2016)
- ***The Industrial Adsorbents Business: Commercial Strategy, Technical and R&D Assessment in Refining, Chemicals/Syngas, Natural Gas and Industrial Gases*** (July, 2013)

However, our clients have made it clear that **there is industry support for a combined study focused on separations and purification on an ongoing basis. 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.**

The increase in product purity requirements, energy costs and GHG regulations have caused refiners, petrochemical/chemical and gas producers to look for efficient ways to find competitive solutions. Improved advanced adsorbents, membranes, and separations processes are the answer! **This newly completed study, The Separations Report, is needed to review new technologies and developments more broadly in order to provide separations users with the knowledge necessary to make important decisions about how to improve their operations over every spectrum. 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_2CC) Program**, include:

- ***Recent Progress in Zeolitic Membranes for Gas Separations and Catalysis*** (December, 2016)
- ***Benchmarking CO_2 Capture Technology (Vol. 3): Update on Selected Pre-/Oxy-Combustion and Post-Combustion Capture Routes*** (September, 2016)
- ***The Intelligence Report: Business Shifts in the Global Catalytic Process Industries, 2015-2021*** (May, 2016)
- ***Specialty Zeolites in Catalysis, 2002-2020: International, Commercial and Technical Progress – A New Era!*** (February, 2014)

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IV. SCOPE AND METHODOLOGY

TCGR's study documents and assesses, on both scientific and techno-economic bases, recent developments in separation technologies and compares 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 in adsorbents and membranes, by type
- Strategic analysis and competitive implications

As depicted in the completed report's actual Table of Contents, which includes "charter" subscriber inputs (see pages 9-22), 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's "charter" subscribers (i.e., those who signed up prior to study launch) provided 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 patent analysis, as well as expert review and analysis of recent trade literature and conference proceedings. 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 new technologies and applications. The potential timeline and extent of replacement are analyzed to understand implications on incumbent technologies and suppliers.

Section VII. Strategic Analysis and Business Recommendations, provides an assessment of the competitive landscape and opportunities for growth.

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 over 30 years of experience.

TCGR's unique background and established global Dialog Group® ensures expert capability and skill level in this study area. TCGR utilized 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 sought 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 areas (i.e., adsorbent/membrane type, application area, etc.) that were 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

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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 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.

The study, **"The Separations Report: Commercial, Technical and R&D Assessment in Refining, Petrochemicals/Syngas, Natural Gas and Industrial Gases"** was completed in October 2017.

Post-production subscribers	after October, 2017	$21,500

The Separations Report: Commercial, Technical and R&D Assessment in Refining, Petrochemicals/Syngas, Natural Gas and Industrial Gases

Report in PDF format, in addition to subscription price	$1,000

**Charter subscribers (those who signed up for the study before its launch) had 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 Past Multi-Client Studies in These Areas:

*Due to the complementary nature of this study to TCGR's reports entitled "**Membranes in Separations: Commercial Advances in Refinery, Petrochemical/Chemical and Industrial Gases Applications"** (November 2016) and **"The Industrial Adsorbents Business: Commercial Strategy, Technical and R&D Assessment in Refining, Chemicals/Syngas, Natural Gas and Industrial Gases"** (July 2013), TCGR is offering a discounted price for "**The Separations Report"** to subscribers of either/both of those studies. Subscribers are requested to contact John J. Murphy at +1.215.628.4447, or John.J.Murphy@catalystgrp.com for further details. When completing the order form, please make sure to indicate your company's subscription to either/both of the earlier reports.*

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Please enter our order for "**The Separations Report: Commercial, Technical and R&D Assessment in Refining, Petrochemicals/Syngas, Natural Gas and Industrial Gases,"** completed in October 2017, as follows:

____ **The Separations Report: Commercial, Technical and R&D Assessment in Refining, Petrochemicals/Syngas, Natural Gas and Industrial Gases**, for $21,500 (post-production).

____ 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 subscribers to either/both of TCGR's earlier multi-client studies addressing ***Membranes in Separations*** (2016) and/or ***Industrial Adsorbents*** (2013) and are therefore entitled to the discounted subscription rate. * * *

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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Name: _____ Title:_____

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FIGURES

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TABLES

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