CATALYSTS AND PROCESSES FOR THE RUBBER & ELASTOMER INDUSTRIES: TECHNOLOGY ADVANCES AND COMMERCIAL/STRATEGIC IMPLICATIONS

MULTI-CLIENT STUDY PROPOSAL

May 2018

TCGR THE CATALYST GROUP RESOURCES™

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Catalysts and Processes for the Rubber & Elastomer Industries: Technology Advances and Commercial/Strategic Implications

I. ABSTRACT

There is substantial opportunity in market development, technological innovation and competitive advantage as a result of recent advances in in the rubber and elastomer industries (e.g., via process efficiency gains/cost reductions as well as products with new or enhanced performance profiles). The markets are growing at attractive rates and the margins on products can be elevated via new or advantaged properties**. In this proposed study, TCGR will provide a comprehensive overview of developments in elastomers/rubbers by type and will assess the progress across the value-chains in their manufacture, including i) catalysts, ii) process technologies, iii) product & applications, and iv) on-purpose monomer technologies of interest for elastomers under use and/or in development.** Focus will be placed on notable technology developers including: Arlanxeo, ExxonMobil, Dow Elastomers, Sibur, LyondellBasell, LG Chem, Sabic/SK Nexlene, TSRC, LCY Chemicals, Bridgestone, Versalis, Bayer and Covestro, etc. along with leaders in catalysts/activators such as Akzo Nobel, Grace, Lanxess/Chemtura, Nippon Alkyls, Solvay, Albemarle and FMC, among others.

With an outlook covering the next 5-10 years, TCGR will consider commercial and technological developments that will provide the report's subscribers with expert information for current business operation and future business planning. By focusing on emerging technologies, TCGR will detail how changes occurring now and expected in the future will impact the elastomer and rubber industries of tomorrow. **A key need/justification for this study, and one that TCGR is uniquely capable of delivering, is a comprehensive technological assessment of rubber/elastomer catalysts, processes and products so that developers and producers can maximize the value of their participation in the industry as it changes to reflect new drivers/factors shaping it.** There are only a few industries where technology plays such an important role in the product's physical and performance properties and differentiation is critical to success. This study will document the commercial opportunities and competitive threats as a result of technology change – it is a "must have" for future success in rubber/elastomer production.

II. INTRODUCTION/BACKGROUND

The rapidly growing car industry, along with healthy growth rates in building & construction, mechanical applications and the shoes/sporting goods markets, have significantly contributed to the growth of rubber/elastomer products in recent years. This trend is expected to continue over the next few years, justifying interest from process licensing and catalyst suppliers to rubber/elastomer manufacturers, as opportunities to yield "premiums" for selected products with

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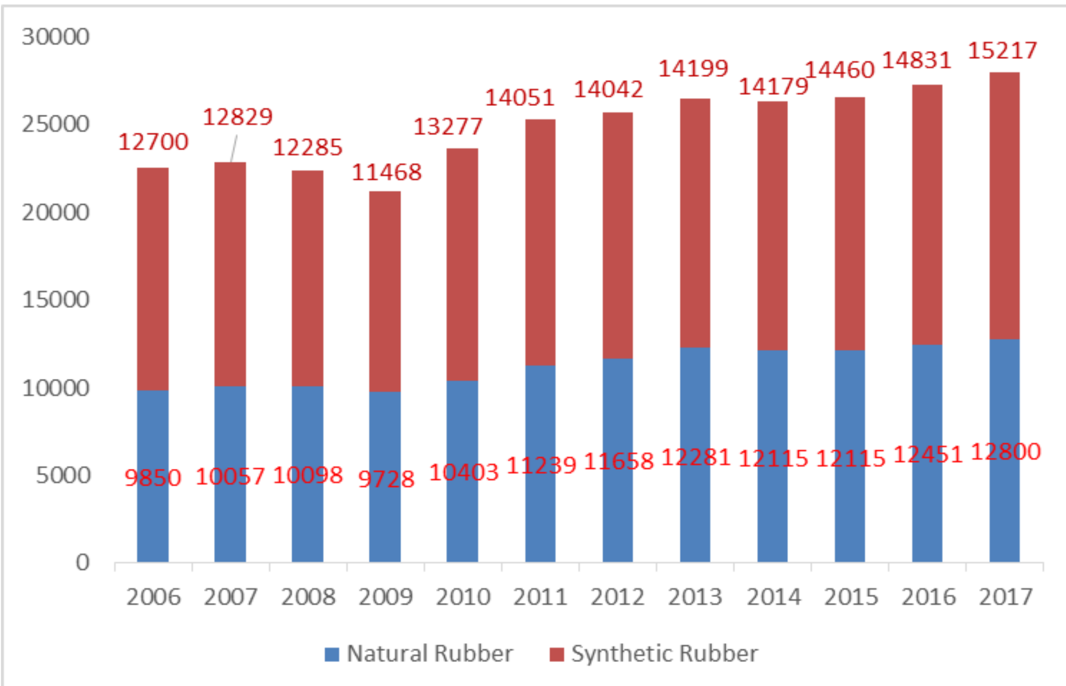
advantaged properties yield improved margins/returns. There is also a drive to improve production efficiencies and reduce costs, heightening margins for these materials sold into competitive markets served globally.

The size of the elastomers/rubbers market is substantial: aggregate elastomers, including both natural and synthetic rubber (NR and SR), constituted a market of about 28 million tons/year (production) in 2017, following only polyolefins, PVC and PET. **Figure 1** depicts global elastomer production over the recent past, with the ratio of natural to synthetic rubber in 2017 at about 46%, reflective of a consistent level over the years.

Figure 1: Global Natural and Synthetic Rubber Production (,000 tons/yr)



Source: IRSG, 2018

In order for elastomers and rubbers to achieve the required performance objectives in their applications, specialized catalysts are used to polymerize the monomers into controlled structures. Since their introduction, ethylene-propylene elastomers (EPR/EPDM), polybutadiene rubber (BR), polyolefin elastomers (POE) and reactor thermoplastic olefins (r-TPO), have been commercially produced using homogeneous catalysts such as vanadium-based or other Ziegler Natta (ZN) catalysts and/or, more recently, well-defined, highly active, homogeneous catalysts, such as ZN neodymium-based catalyst for very high cis BR or classical metallocenes and/or advanced post-metallocene single-sites catalysts (SSC), targeted at production of new types of EP elastomers with fast cure and high degrees of cure at very high yields.

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As documented in TCGR's biennial catalyst and process licensing industry report entitled ***"The Intelligence Report: Business Shifts in the Global Catalytic Process Industries, 2017-2023,"*** catalysts for elastomers/rubbers are an important class in the global catalyst market: **Table 1**, taken from the 2018 edition of TCGR's report, depicts the breakdown of the global polymerization catalysts market value. The elastomer catalyst value is substantial in comparison with other polymerization catalyst segments; in this proposed TCGR study, the specific value of this catalyst segment and its composition by elastomer/rubber type, will be documented and assessed.

Table 1: Worldwide Catalyst Market - Polymerization (US $ MIL)

Polymer	**2017**	**2023**	**AAGR 2017-2023**
Polyethylene	1123	1407	4.2%
Polypropylene	869	1104	4.5%
PVC	284	318	2.0%
PS & ABS	146	167	2.3%
PET	732	1000	6.1%
Elastomer & Other	**930**	**1096**	**3.0%**
TOTAL	4083	5091	4.1%

Among the numerous opportunities in these areas, technology providers and catalyst producers can address the need for improved production efficiencies (via reduced production costs) and enhanced, or even unique, performance properties. In particular, despite the rapid significant growth of the rubber product global use, the SR industry has suffered persistent overcapacity that has resulted in compressed margins. The other elastomer and rubber industries are also intensely competitive in terms of basic costs, so producers strive to shave their manufacturing costs by a number of approaches, including: (i) increasing reactor productivity; (ii) increasing plant availability via debottlenecking it to the limits of process equipment; and (iii) using swing process technologies to increase the production flexibility vs. the market demand.

There are limits to cost reduction through gains in efficiency, so producers also strive to differentiate their products in terms of performance and match to market needs. Differentiated products achieve higher margins and higher margins lead to higher profitability and greater competitive strength. Examples of such differentiated products are the functionalized solution styrene butadiene rubbers, very high cis neodymium butadiene rubbers, high vinyl styrene butadiene rubber, or EPDM rubbers produced either by suspension polymerization, by which extremely high molecular weights can be achieved, or by solution polymerization, by which truly amorphous grades can be produced, or by gas phase process.

As an example, EPDM catalyst innovation has spurred concurrent innovation in process and product technology, driving a virtuous innovation circle and becoming a proven/reliable means to achieve process efficiency (cost-competitiveness) as well as product differentiation. **Figure 2** provides a timetable of EPDM combined technology (catalyst/process/product) innovation cycles. It is understood that changes in technology have important strategic implications on the competitive landscape and outlook for technology developers and producers.

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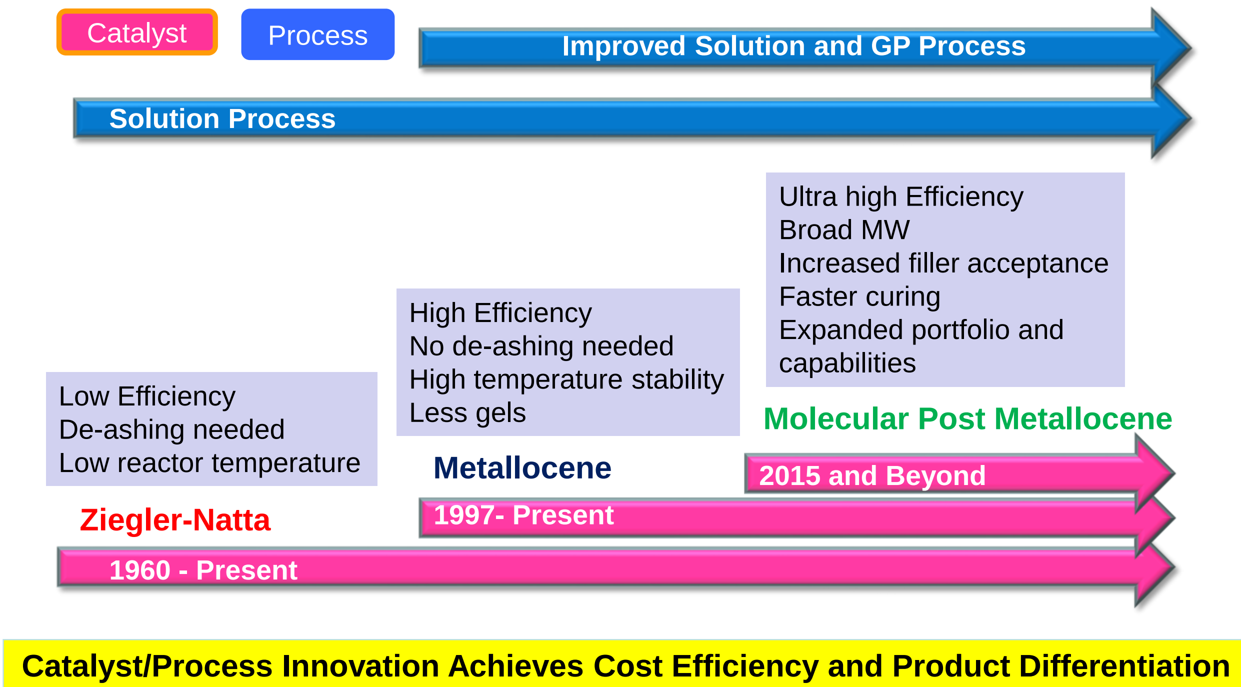
Figure 2: EPDM Catalyst/Process Innovation



Producers of elastomers generally belong to the following three groups:

- Vertically integrated elastomer/tire producers (e.g. Bridgestone, Firestone, Goodyear, Michelin, Sumitomo, Yokohama Rubber Co., Toyo Tire & Rubber, Kumho, etc.)
- Independent elastomer producers (e.g. Lanxess/Arlanxeo, ExxonMobil, Sinopec, PetroChina, Versalis, Sibur, Trinseo, Sabic, etc.)
- Thermoplastic elastomers (TPE) producers, generally integrated with polyolefin production (e.g. Dow Elastomers, LyondellBasell, ExxonMobil, Mitsui Chemical, Borealis, etc.)

For major independent producers, elastomers are a strategic core business to be maintained and exploited through an active pursuit of catalyst-process innovation and product differentiation. The elastomer/tire integrated producers usually focus on elastomers more to secure a stable raw material supply for use in the company’s strategic tire products, allowing for more streamlined operations.

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Regarding the catalyst suppliers (e.g., initiators, ZN, SSC/metallocene, co-catalysts), they can be categorized as:

- Independent third party suppliers (e.g. Akzo Nobel, Albemarle, Grace, Comar, Evraz, Solvay, Nippon Alkyls, etc.); and
- Integrated catalyst/elastomer producers (e.g. Lanxess/Chemtura, Dow, LyondellBasell, Sinopec, Mitsui Chemicals, Sumitomo, etc.)

As is the case in other/related polymer industries, elastomer producers are served by a network of catalyst and technology suppliers; **Figure 3** depicts the elastomer catalyst and technology market structure. The elastomer/rubber catalyst and technology markets, as noted earlier, are very competitive with a lot of M&A, joint venture and cooperative agreements established in the marketplace over the years.

Figure 3: Elastomer Technology Industry Structure

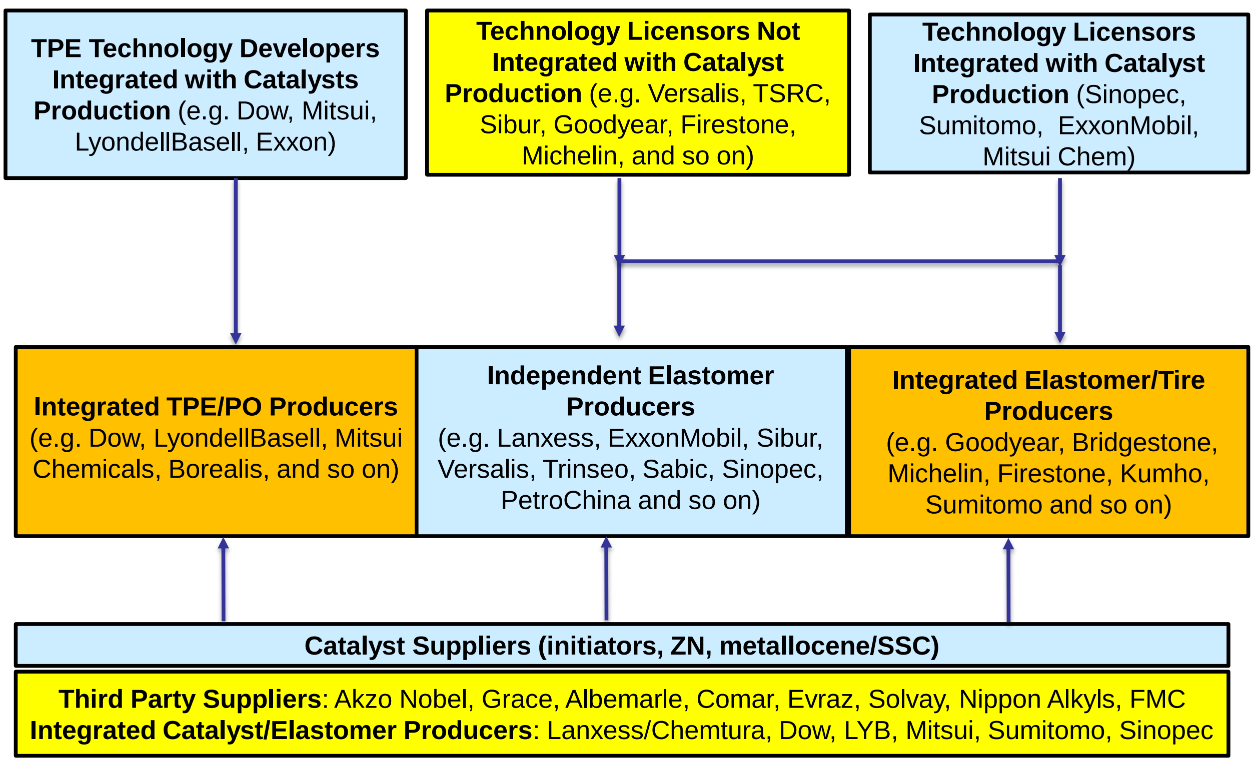
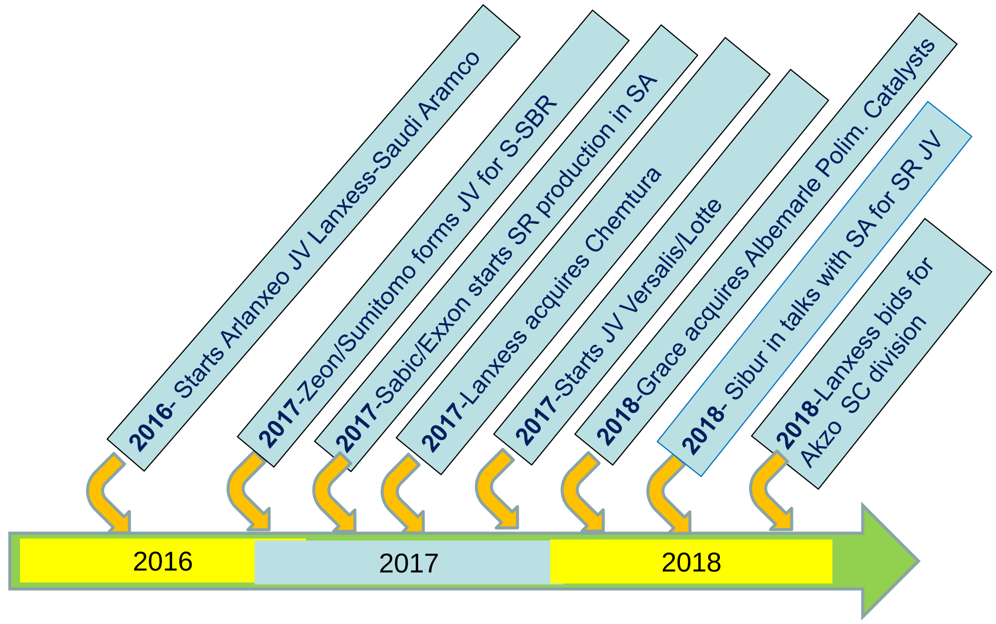


Figure 4 provides a timetable of most recent M&A and/or JV moves that have spurred the elastomer/rubber industries. It is worth noting the significant activities and efforts of Lanxess to grow in particular in the specialty chemicals segment including initiators, catalysts and co-catalysts for polymers.

Figure 4: Recent Elastomer/Technology M&As



III. NEED & JUSTIFICATION

Along the value chain in elastomer/rubber production, there are at least three major challenging issues that will impact the competitive landscape, as follows:

- on the feedstock side - monomer volatility and supply/production route (e.g. butadiene)
- on the technology side - catalyst and process advances to achieve cost efficiencies and provide product differentiation
- on the end-products side – penetration by electric and automated cars (including extended mobility and car digitalization)

Regarding rubber/elastomer feedstocks, the industry is currently experiencing a high degree of volatility in the monomer supply chain particularly for butadiene, propylene and styrene. There is also a movement towards the production of monomers such as butadiene, aromatics and olefins directly from crude oil, ethane, methane and so on through non-conventional on-purpose technologies opposed to via the traditional thermal cracking of naphtha (for olefins and butadiene) and via traditional refining reforming (for aromatics). This is being driven by numerous factors, the most important of which is the imbalance between demand for oil-derived liquid fuels (diesel, gasoline) and the more rapid growth in markets for petrochemicals like olefins (ethylene, propylene), aromatics (BTX) and specialty intermediate streams like C4s and higher olefins. The imbalance has made the idea of using crude (or alternatively shale gas, methane, and coal) as a direct feedstock more appealing for integrated producers of fuels and chemicals as well as direct chemical companies.

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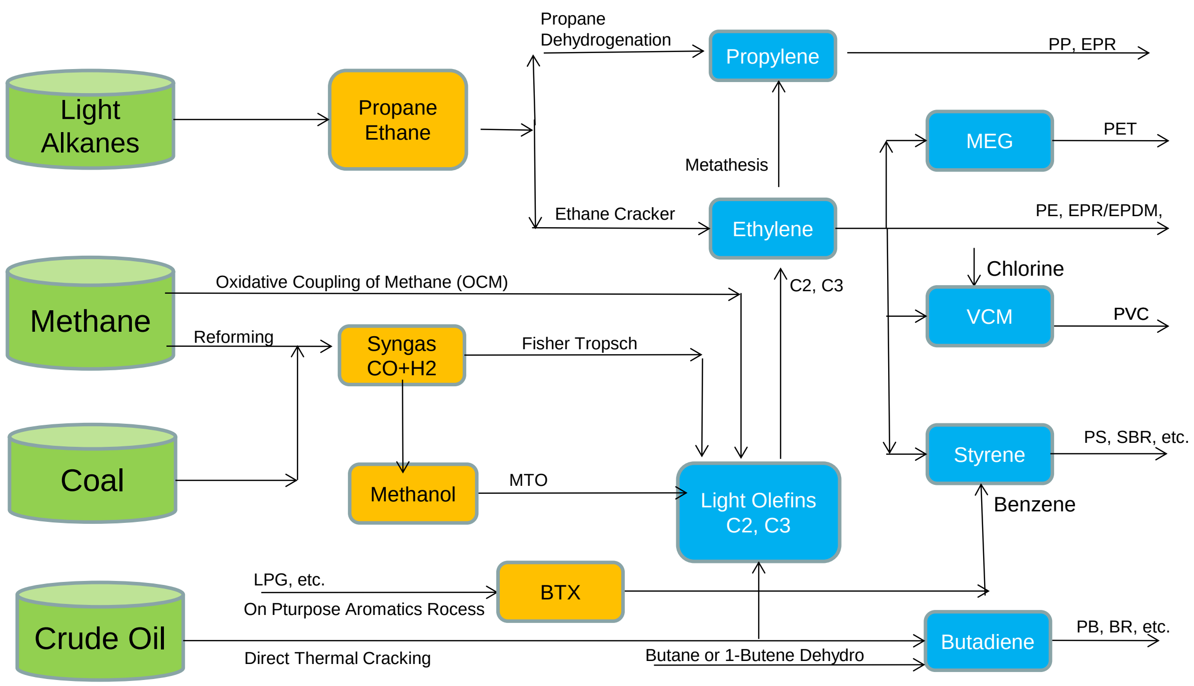
Figure 5 summarizes some non-conventional on-purpose process routes, both in commercial or developmental stage, to produce the monomers of interest for elastomers such as butadiene, propylene, styrene and ethylene.

Figure 5: Unconventional Technologies for Main Monomers in Elastomer/Rubber Production from Various Feedstock



It is clear from the above that there is substantial opportunity in market development, technological innovation and competitive advantage (e.g., via process efficiency gains/cost reductions) in the rubber and elastomer industries. There are also challenges presenting noteworthy hurdles, including the following issues/questions.

A relative shortage of butadiene, propylene and styrene, along with volatility of prices, especially for butadiene, are still very much influencing the rubber industry. However, a broad range of new non-conventional on-purpose technologies for monomers used in elastomer/rubber production, some of which are still in the developmental stage, are changing the technology landscape. Key questions include:

- How will the elastomer/rubber market adjust to (or develop) a more stable supply/demand balance? What technologies for on-purpose or non-conventional supplies are ready (or if not, when can they be expected)?

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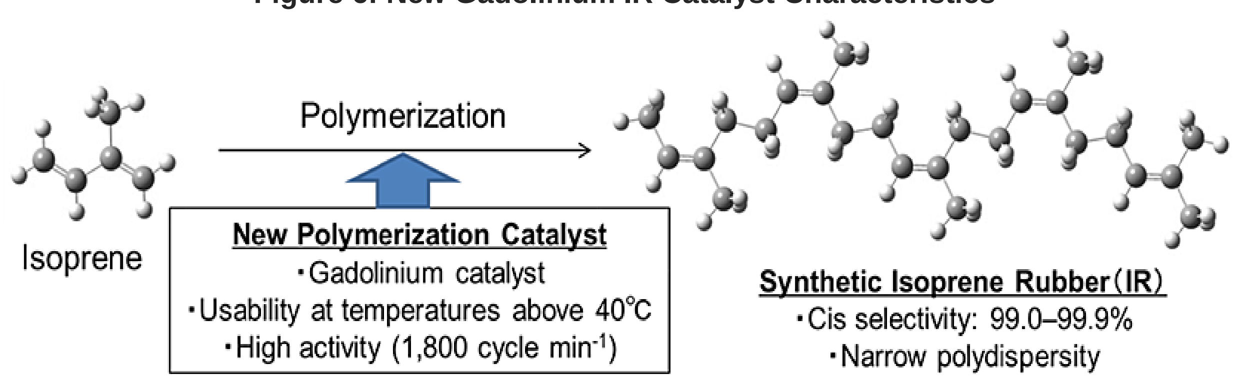
EP rubbers and EPDM are in high demand for non-tire applications due to their excellent properties driven by integrated catalyst and process development. Various catalyst technology generations, such as Ziegler Natta, metallocene (e.g. ExxonMobil, Mitsui Chemical) and post metallocene catalysts (e.g. Lanxess/Arlanxeo and Dow Elastomers) are used in combination with solution, gas phase and bulk processes to produce EP rubbers. Current post-metallocene catalysts are targeted at production of new types of EP elastomers with low to ultra-high Mooney, fast cure and high degrees of cure at very high yields (more efficiency).

- Despite these excellent results, what's next? Which new catalyst compositions or process technologies may improve further the various synthetic rubber products as SBR, BR, EPDMs, IIR/HIIR, NR, CR, SEBS, POE or R-TPO, to comply with the new requirements of the tire/automotive, pharmaceutical, building & construction, mechanical, and other industries? As examples of "next" technologies to be pursued, note the following:
    - Bridgestone is developing a polyisoprene (IR) rubber that has the potential to create the next-generation IR with performance surpassing that of natural rubber, through a precise molecular structure control utilizing a new proprietary Gadolinium polymerization catalyst (see the characteristics of such a catalyst in **Figure 6**) or
    - the significant catalyst/process advancements being achieved by technology leaders such as ExxonMobil and Arlanxeo to develop a new breakthrough butyl/halobutyl rubber technology to enable a higher reaction temperature than previously possible (-100 °C) and other improvements for a more efficient production of IIR/HIIR rubber.

Figure 6: New Gadolinium IR Catalyst Characteristics



Source: Bridgestone 2017

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Despite the strong and steady growth rates for rubber/elastomer products globally, the industry remains at overcapacity which shrinks margins. Lanxess, a global leader in synthetic rubber products, was partly turning away from rubber business in favor of specialty chemical businesses that are less cyclical, and have higher EBITDA margins. Lanxess in 2016 packaged its synthetic rubber and high-performance elastomer businesses into a business segment called "Arlanxeo" and sold 50% of it into a JV with Saudi Aramco (also taking advantage of better access to raw materials).

- Will Lanxess choose to continue to consolidate the synthetic rubber space and sell the remainder of the business to Saudi Aramco?

Access to technology is always a vital feature for an industry.

- Is elastomer technology licensing accessible to newcomers or there is a barrier to entry or growth in the elastomer industry? Who are the leaders, the followers and the potential up-and-comers? How will the competitive landscape be different because of technical capabilities/offerings of the various catalyst suppliers and/or process licensors?

Macro trends like the "circular economy" and overall sustainability in the rubbers/elastomers industries includes product recycling & up-cycling, development of new bio-derived materials, further enhancement of green tires, etc.

- How will the industries participate and which ones will lead the way? Which bio-derived elastomers will grow the most quickly and why? Which companies have the technology to do so and will they license it (or will others be required to develop it independently)?

The largest end use for elastomers/rubbers - the automobile industry - has begun to shift substantially towards electric/hybrid models. One consequence will be heavier vehicles due to new long-life batteries; after decades of progressive light weighting, new challenges now impact the tire and the elastomeric materials' industry.

- What will the impacts on elastomer/rubber usage as a result of light weighting in the car industry? What impact will these new types of vehicles and environment have on the tire and elastomer industry? What are the new requirements for novel elastomers from such applications?

A comprehensive and analytical assessment of these and related challenges/opportunities is justified in order to document the full breadth and depth of their competitive and strategic implications. In this report, the major rubber/elastomer market/technology issues will be analyzed and discussed from a quantitative (i.e. market size/growth) and competitive/strategic perspective. Among the critical topics to be included are:

- In reaction to industry commoditization and possible market consolidation, which companies will be buying and which will be vulnerable to acquisition?
- As advances in catalyst and process technology respond to the market demand of sustainability, efficiency, differentiation, etc., which companies will be focusing on which areas/materials and what are the potential impacts and timing on markets and competitors?

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- What are the impacts of non-conventional on-purpose technologies for elastomers monomers on feedstock volatility/availability (e. g. PDH for propylene, BDH for butadiene, ethanol dehydration or metathesis for ethylene, etc.) and what are their readiness levels (for those still in the developmental stage)?
- What are the impacts of new performance requirements/drivers (e.g., new cold adhesives, such as SEBS or R-TPO, or liquid membranes) in other major elastomer/rubber applications (e.g. roofing/waterproofing, wires and cable, soft sheets, flexible pipes, etc.)?
- What are the implications for technology developers and producers (for both elastomers/rubbers and olefins/monomers) of market competitive landscape and outlook changes?
- To what degree will the anticipated changes in technology affect rubber/elastomer projects planning, including modifications to existing facilities as well as new/grassroots projects?
- How can/should the incoming triple car revolution (hybrid/electric vehicles, automated/self-driving cars and extended mobility) be considered relative to tire and automotive rubber materials?

As noted earlier, a key need/justification for this study (and one that TCGR is uniquely capable of delivering), is a comprehensive technological assessment of rubber/elastomer catalysts, processes and products so that developers and producers can maximize the value of their participation in the industry as it changes to reflect new drivers/factors shaping it. There are only a few industries where technology plays such an important role in the product's physical and performance properties and differentiation is critical to success. This study will document the commercial opportunities and competitive threats as a result of technology change – it is a "must have" for future success in rubber/elastomer production.

IV. SCOPE AND METHODOLOGY

The study's proposed scope will follow the preliminary Table of Contents depicted on p. 13. After a brief "Introduction" section providing the needed background, as well as an "Executive Summary," the report will provide the following sections:

Section III will detail the synthetic rubber/elastomer global market in terms of size and growth (that's NR and SR major market segments, global supply-demand, by geographic region and capacity, etc.) along with market trends and opportunities/challenges. The section will provide a detailed delineation of market trends and in particular of: a) the new demanding technology requirements for elastomers coming from incoming automotive and other markets breakthroughs, and b) circular economy and elastomer recycling/up-cycling as being implemented by the elastomeric industry. Particular focus will be given to the rubber performance requirements, applications and markets by type and to the major producer &

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technology leader profiles, their projects and their technology innovation approach. The catalyst/technology market structure and competitive/strategic landscape, including the current value of the elastomer catalyst segment, will be analyzed. Section breadth encompasses the entirety of the elastomer end products and catalyst/technology market, including an indication of access to production technology by licensing (e.g. technologies for license, technologies for exclusive use in-house, etc.), globally. Analysis will include both general and special purpose elastomer materials.

Section IV will provide a deep review of both technical and competitive/strategic information, designed to identify advances in new non-conventional on-purpose technologies for monomers of interest for the production of elastomers/rubbers (e.g. butadiene, propylene, styrene and ethylene). These new on-purpose technologies are coupled to various types of available feedstock such as shale gas, methane, crude oil or coal and are in various stages of development. The following technologies will be examined and discussed: a) on-purpose routes to butadiene as butane or 1-butene dehydrogenation (BDH); b) propylene from propane dehydrogenation (PDH); c) on-purpose technologies to produce styrene such as LPG to aromatics, CCR platforming, or bio-aromatics; and d) ethylene from ethanol dehydration, metathesis or oxidative coupling of methane (OCM). This section will review the unconventional technologies and feedstocks for producing elastomer monomers, verify their growing use, assess the readiness of developmental technology and their capability to alleviate the monomer shortage and related volatility, providing subscribers with expert information for future business planning.

Section V will introduce the major catalyst systems (e.g. initiators, Ziegler Natta, and SSC-metallocene and molecular post-metallocene catalysts) for elastomer/rubber production and identify their developments and advances along the innovation cycles, the current innovative contribution to elastomer cost/performance capabilities and their potential for new technology breakthroughs. An indication of the industry participants' technical profiles will be provided with indications of their relationships within the value chain, reflecting potential advantages or liabilities.

Section VI will address both technical and competitive information, designed to identify advances in elastomer's catalyst, process technology, products and applications for main rubbers/elastomers, regarding the capabilities and advances of elastomers technologies (catalysts, processes, and products) by type and by major technology leaders. This will be achieved through a comprehensive review and analysis of the technical literature (including patents, conference proceedings, technical/journal articles, etc.), to include both industrial and noteworthy academic/institutional advances, considering elastomer-specific developments (e.g. operating conditions changes due to catalyst activity levels, various catalysts generations, etc.) performed by major technology leaders. This section will assess both technical and strategic information, designed to identify the competitive environment for exploring novel elastomer and applications that allow participants to address the market challenges and opportunities in the years ahead.

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Lastly, **Section VII** will include competitive/strategic assessments and recommendations on the subjects of critical importance to the rubber/elastomer industries.

TCGR will deliver this report in its “multi-client” study format in order to effectively and efficiently capture the most important market, competitive and strategic technology developments and trends for use by decision-makers. Beyond the resources used therein, TCGR also utilizes publicly available and in-house information to complete the deliverables as well as patent searches, technical literature reviews, and in-field interviews with catalyst manufacturers and process licensors.

In addition to its in-house expertise, TCGR will utilize a combination of Dialog Group® expert(s) to implement the study analysis and assist with completing this report. These industry expert(s) have deep experience in the elastomer, rubber and polymer industries, from both commercial and technical perspectives, with expertise in catalyst development and production as well as process technology licensing and production. In this analysis, TCGR will augment its in-house expertise through the contributions of, among others, Dr. Salvatore Ali. Dr. Ali is an independent consultant whose deep industrial practice spanned most aspects of the polymer and elastomer industry. He spent a career of over 30 years with LyondellBasell and predecessors companies (Basell, Montell, Himont, Technipol/Montedison) and Tecnimont, in various international locations, covering in those companies top management positions as, inter alia, Director Catalyst/Process Development, VP Catalyst Business and VP Technology Licensing.

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Preliminary Table of Contents

CATALYSTS AND PROCESSES FOR THE RUBBER & ELASTOMER INDUSTRIES: TECHNOLOGY ADVANCES AND COMMERCIAL/STRATEGIC IMPLICATIONS

** Charter subscribers (those who sign up for the study before June 15, 2018) will have the opportunity to work with TCGR to further refine the scope of the report by nominating specific companies and/or technologies as well as delineating areas of particular interest for inclusion in the assessment.*

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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
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- Provide leading information and knowledge through:
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The client-confidential assignments conducted by The Catalyst Group include projects in:

- Reinventing R&D pipelines
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- 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 rubber/elastomer production, polyolefin producers involved in elastomeric related/enabling technologies (e.g. TPE including POE and/or r-TPO), EPC contractors interested in building rubber/elastomer plants, feedstock providers that want to understand or invest in downstream, etc. TCGR's report, based on technology evaluations, market assessments and interviews with key players will assess results and provide opinions beyond the 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, **"Catalysts and Processes for The Rubber & Elastomer Industries: Technology Advances and Commercial/Strategic Implications"** is expected to be available in September/October 2018.

"Charter" subscribers*	before June 15, 2018	US$18,500

Catalysts and Processes for the Rubber & Elastomer Industries: Technology Advances and Commercial/Strategic Implications

Post-launch subscribers	after June 15, 2018	US$21,500

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

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