UNCONVENTIONAL CATALYTIC OLEFINS PRODUCTION: COMMERCIAL VISION AND BREAKOUT?

MULTI-CLIENT STUDY PRESENTATION

(Study completed January 2013)

TCGR THE CATALYST GROUP RESOURCES™

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I. BACKGROUND

Thermal steam cracking and refinery fluid catalytic cracking (FCC) are the main conventional processes for the production of light olefins. Demand for C_2= and C_3= exceeds 200 MIL mt/yr. By 2015, it is forecast over 300 steam cracking plants will exist with exceeding 175 MIL mt/yr, with over 400 FCC units, exceeding 15 BIL BPSD (see Tables 1-3 below).

Table 1
Top Ethylene Producers and Refiners with Largest FCC Capacity (True, 2011; Nieskens, 2008)

World Top Ethylene Producers			World Top Refiners with Largest FCC	
Company	Capacity, million t/yr		Company	Capacity, million t/yr
Dow Chemical	10.5		ExxonMobil	60.5
SABIC	10.3		Shell	52.0
ExxonMobil	8.6		Sinopec	35.5
Sinopec	7.3		Valero	35.1
Shell	6.0		BP	32.2
Chevron	5.4		Petrobras	25.0
LyondellBasell	4.7		Total	20.7
World Capacity 138 million tpy			**World Capacity 762 million tpy**	

Table 2
World Production for Ethylene and Propylene: 2010 (Yim, 2011)

Ethylene Production			Propylene Production	
Steam Cracker Feedstock	**%**		**Production Source**	**%**
Naphtha	50		Steam Cracking	57
Ethane	32		FCC/Splitters	30
Propane	8		Propane Dehydrogenation, PDH	4
Butane	4		Metathesis	4
Gas Oil	4		High Severity FCC	3
Others	2		Others	2
World Production ~ 122 million tpy			**World Production ~ 75 million tpy**	

Table 3
World End-Use for Ethylene and Propylene: 2010 (Yim, 2011)

Ethylene Demand			Propylene Demand	
Demand/Use	**%**		**Demand/Use**	**%**
Polyethylene	61		Polypropylene	67
Ethylene Oxide/MEG	14		Propylene Oxide	8
Ethylene Dichloride/PVC	12		Oxo Alcohol	8
Ethyl Benzene/Styrene	6		Acrylonitrile	7
Alpha Olefins	3		Cumene	4
Others	5		Acetic Acid	4

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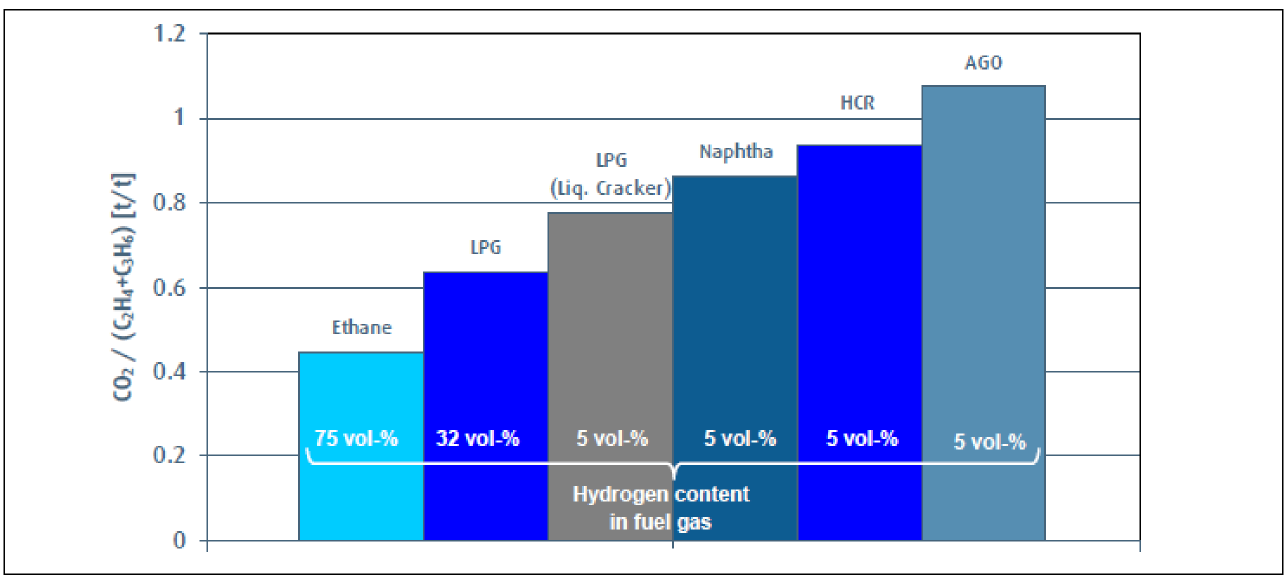
They are vital feedstocks for polyolefins (PE, PP) and key intermediate/feedstock chemicals: ED/PVC, EO and derivatives, PO and derivatives, styrene, acrylonitrile and cumene (see Table 3 above) for even higher demand in final consumer products.

Thermal steam cracking and the FCC processes are both mature technologies. One limit to thermal crackers has been the 0.4 to 0.6 propylene/ethylene weight ratio. This has prompted an imbalance in propylene supply, which has historically grown at a faster rate (+4-6% pa) than ethylene and driven the development and industrial adoption of C_3= FCC additives, new FCC processes to increase C_3= yield using double risers e.g., Shell MILOS, Sinopec DCC and the commercialization of HSFCC by Aramco/PEC/Axens and INDMAX by IOC/Lummus, although, except for DCC, these have yet to reach any substantial industry capacity. As highlighted in Table 3, this has also forced increased adoption of alternative C3= production routes like propane dehydrogenation (PDH), metathesis and increasingly by MTP, MTO, DMETO in China.

Very little has changed for thermal crackers (with some reduced coking and improved separations). In particular, crackers suffer from inefficiency due to high temperature/high energy costs (coils 850°C), complex/costly separations and significant CO_2 emissions. As shown in Figure 1 below, the average CO_2 emission is 0.8 ton per ton of ethylene/propylene from naphtha and extreme temperatures increase costs in materials, operability, control and maintenance.

Figure 1
Typical Values of Specific CO_2 Emissions from Thermal Cracking Furnaces as a Function of Feedstock (Schmidt et al., 2010)



Other commercial changes have also prompted the need for olefin production process improvements:

- The increase of resid feedstocks to reduce cost(s) and equally the switch to "ethane" historically in the Middle East but now a "game changer" in the U.S. due to

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unconventional shale gas. This is also anticipated to grow internationally, thus compounding the need for more C3= flexible processing in existing and new processes.

- In the refining industry the reduced demand for gasoline vs. diesel will favor a change in FCC unit operations(s) toward petrochemicals/olefins production. However, due to both costs and environmental regulations (FCC units emit 15-20% of complex emissions) unique/improved solutions will need to be adopted.

As a result, there is a significant commercial need to develop and adopt more flexible, more efficient environmentally friendly and less costly catalytic olefin production technologies. Interestingly some new technologies have been emerging and commercializing during the last five (5) years that demonstrate unique solutions are on the horizon. These include:

- *SK Innovations/KBR ACO Process* – catalytically cracks naphtha at 650°C with 65 wt% light olefins yield. The partners claim reduced energy needs of 20%, reduced investment of 30%, reduced CO_2 emissions and at C_2= production cost 20% lower, than thermal cracking.

- *ExxonMobil's* PCC Process – claims improved costs and olefins naphtha yields.

- *Aither Chemicals* – has a process to co-produce ethylene and acetic acid from ethane. Based on Exothane, it claims C_2= is produced at substantially lower energy costs and CO_2 emissions, using oxygen with a catalyst.

- *UOP* has announced it is seeking partners to pilot methane to ethylene technology that could save 40% of the investment cost.

In addition to processes that are commercializing, significant R&D is underway in the catalytic conversion of methane-to-olefins (MTO).

This newly updated report covers some very important commercial topics for executives and technologists, critically important to business planning and decision making over the next few years. The topics examined include:

- An in-depth review and vision on the commercial landscape for olefins productions 2012 to 2020 and beyond. Reports to date have benchmarked past and today's status (with planned licenses on existing processes) i.e., the status quo. Little vision has been applied to examining the question about next generation evolutionary olefins production technologies.

- Examination of the key economic and market considerations that will affect the decision speed and pace of the adoption of new catalytic olefin production routes, e.g. feedstocks, regulations, and efficiency drivers.

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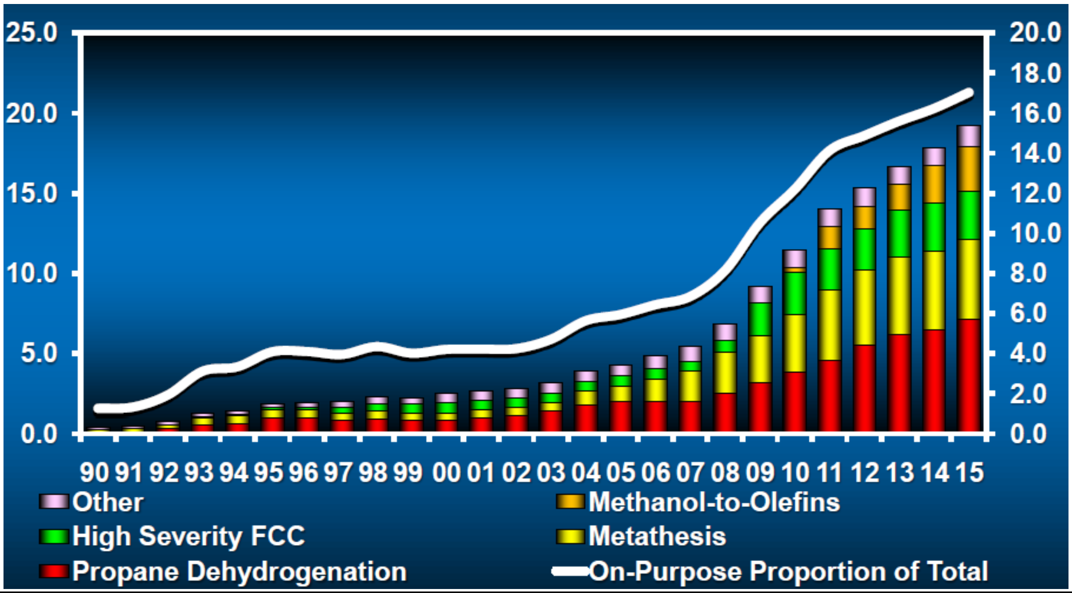
II. THE NEED FOR THE STUDY

The fundamental important outstanding question is, can catalytic olefins production supersede/displace thermal olefin steam crackers in the next decade, based on higher yield (dial-in selectivity), lower investment cost and reduced CO_2 emissions with higher energy efficiency?

This visionary study, with enormous commercial implications, answers that question. It is a large, very complex undertaking. For example, to-date it is assumed on-purpose catalytic C_3= production technologies are the economic solution/choice (see Figure 2). However, this has been examined to determine whether incremental costs to address the C_2= vs. C_3= imbalance, are the only advantages.

Figure 2
Projected Increase in Demand for On-purpose Propylene from Various Routes (Yim, 2011)



To date, the FCC approach (while very successful for C_3=) has not solved the economical recovery of C_2=. Can this be changed?

This study update, ***"Unconventional Catalytic Olefins Production: Commercial Vision and Breakout?"*** compliments an ongoing portfolio of similarly well-received studies that The Catalyst Group Resources (TCGR) has delivered to clients over recent years. This growing experience demonstrates TCGR's unique capability, resources, and expertise to deliver exceptional insight.

Past multi-client studies and current membership-directed programs include:

- Advances in Catalytic Production of Olefins – report exclusively for members of TCGR's Catalytic Advances Program, CAP (March, 2012).

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- Alternative Energy and Fuels Technology: Emerging Catalytic Processes to Improve Efficiencies and Yield – Volume 1 (August 2005); Volume 2 (September 2005).
- Syngas Production and Conversion to Products: A Strategic Assessment of the Technologies, Markets and Competitive Landscape – Volume 1 (March, 2007); Volume 2 (April, 2007).
- New Technology in Olefins Production – report exclusively for members of TCGR's Catalytic Advances Program, CAP (October, 2004).

References:

Nieskens, M., MILOS: Shell's Ultimate Flexible FCC Technology in Delivering Diesel/Propylene, Presented at NPRA – Annual Meeting, March **2008**, San Diego.

Schmidt, G.; S. Ulzama, S.; C. Geipel, C., Cracking Furnace Technology, Presented at Linde's Olefin Academy Conference, Nov. **2010**, Munich.

True, W. R., Oil Gas J., July 4, **2011**, 105.

Yim, J., Asia Olefins Market Outlook, Presented at 11th Asia Petrochemical Industry Conference (APIC), May **2011**, Fukuoka.

III. SCOPE AND METHODOLOGY

TCGR's study begins by benchmarking the FCC and thermal steam crackers to meet existing economic and technical targets – the status quo. The environmental, yield/selectivity, productivity and energy efficiency targets required in the future to displace/supersede existing investments, are then determined. Avenues for improvement(s) are documented. This platform, established in Chapter IV, serves as the basis for subsequent chapters.

Developing processes and emerging commercial technologies of importance, and the likely timing of their commercialization industrially, are presented in Chapters V and VI, as is R&D from academic and government laboratories, including those in China.

Additional unique value from TCGR's study and analysis is presented in Chapters VII and VIII, where TCGR examines how different companies can position themselves to best take advantage of this opportunity. As a result, business leaders receive valuable competitive intelligence in understanding the commercial opportunities that can be derived from the rapidly changing dynamics.

For those that understand and appreciate this study undertaking, you know how important and critically timely this evaluation is! We are standing at a critical crossroads as it pertains to catalytic olefins production. The next ten years are certain to be telling. Thus, TCGR's study is warranted.

In order to heighten the value-added from study participation, TCGR worked with "charter" subscribers (i.e., those who signed up for the study prior to its formal "launch") in order to define the scope of the report by delineating areas of particular interest for inclusion in the assessment. For details on the study scope, the report's actual Table of Contents appears on the following pages.

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FIGURES

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TABLES

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IV. 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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V. DELIVERABLES AND PRICING

This report is timely and strategically important to those industry participants and observers considering investment, as well as to process technology companies evaluating the olefins production and/or 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.

The study, "***Unconventional Catalytic Olefins Production: Commercial Vision and Breakout?***" was completed in January 2013 and is available for immediate delivery in both printed and electronic (PDF on CD) formats.

Unconventional Catalytic Olefins Production: Commercial Vision and Breakout? (completed January 2013)	$22,000
Report in PDF format, in addition to subscription price	$1,000

* * * Notice to Members of TCGR's **Catalytic Advances Program (CAP)** * * *

*This multi-client report is distinct from, and addresses issues different than, the recently completed (March 2012) CAP technical report entitled **"Advances in Catalytic Production of Olefins."** Whereas the CAP report is a detailed assessment of the "state-of-the-art" in technologies, this multi-client study takes a commercial and strategic approach to a range of new olefin production technologies and their prospects relative to current technologies. In addition to coverage of the recent advancements, this report emphasizes commercial considerations, including suppliers, risks, the competitive landscape along with factors for success in the future market.*

Due to the complementary nature of this study to the CAP technical report, we are offering a discounted price to CAP members. CAP members are requested to contact Matthew A. Colquitt at +1.215.628.4447, or Matthew.A.Colquitt@catalystgrp.com, for further details. When completing the order form, please make sure to indicate your company's membership in CAP.

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