

**UNCONVENTIONAL CATALYTIC OLEFINS PRODUCTION:
COMMERCIAL VISION AND BREAKOUT?**

MULTI-CLIENT STUDY PRESENTATION

(Study completed January 2013)



UNCONVENTIONAL CATALYTIC OLEFINS PRODUCTION: COMMERCIAL VISION AND BREAKOUT?

I. BACKGROUND

Thermal steam cracking and refinery fluid catalytic cracking (FCC) are the main conventional processes for the production of light olefins. Demand for C₂= and C₃= 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)**

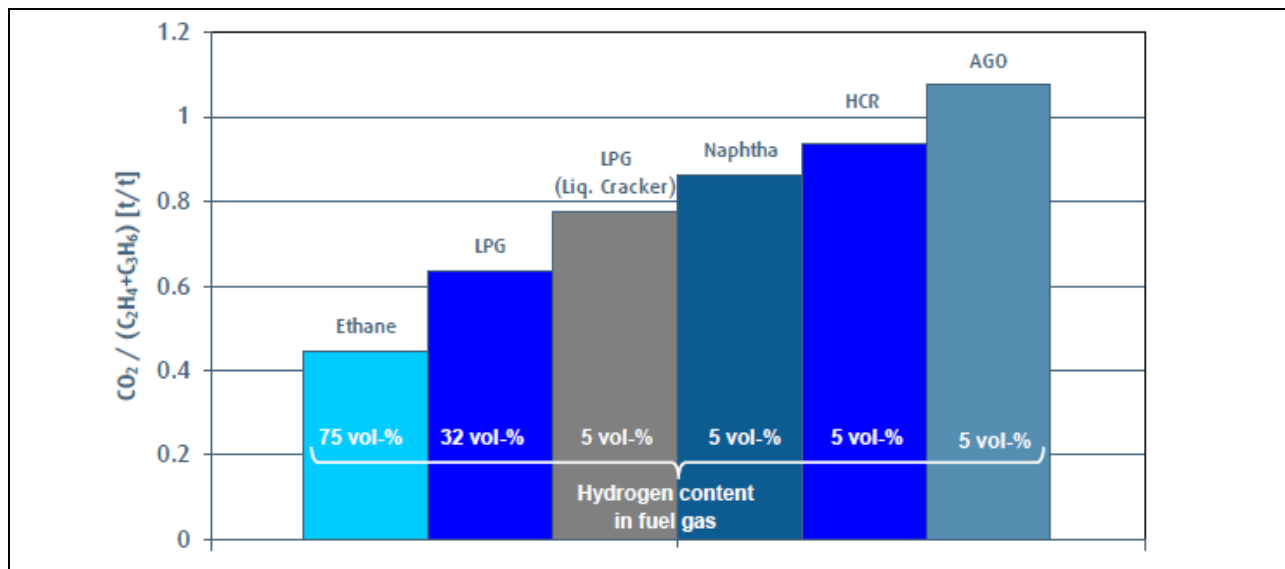
Ethylene Demand		Propylene Demand	
Demand/Use	%	Demand/Use	%
Polyethylene	61	Polypropylene	67
Ethylene Oxide/MEG	14	Propylene Oxide	8
Ethylene Dichloride/PVC	12	Oxo Alcohol	8
Ethyl Benzene/Styrene	6	Acrylonitrile	7
Alpha Olefins	3	Cumene	4
Others	5	Acetic Acid	4

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 C₃= FCC additives, new FCC processes to increase C₃= 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 CO₂ emissions. As shown in Figure 1 below, the average CO₂ 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 CO₂ 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

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 CO₂ emissions and at C₂= 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 C₂= is produced at substantially lower energy costs and CO₂ 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).

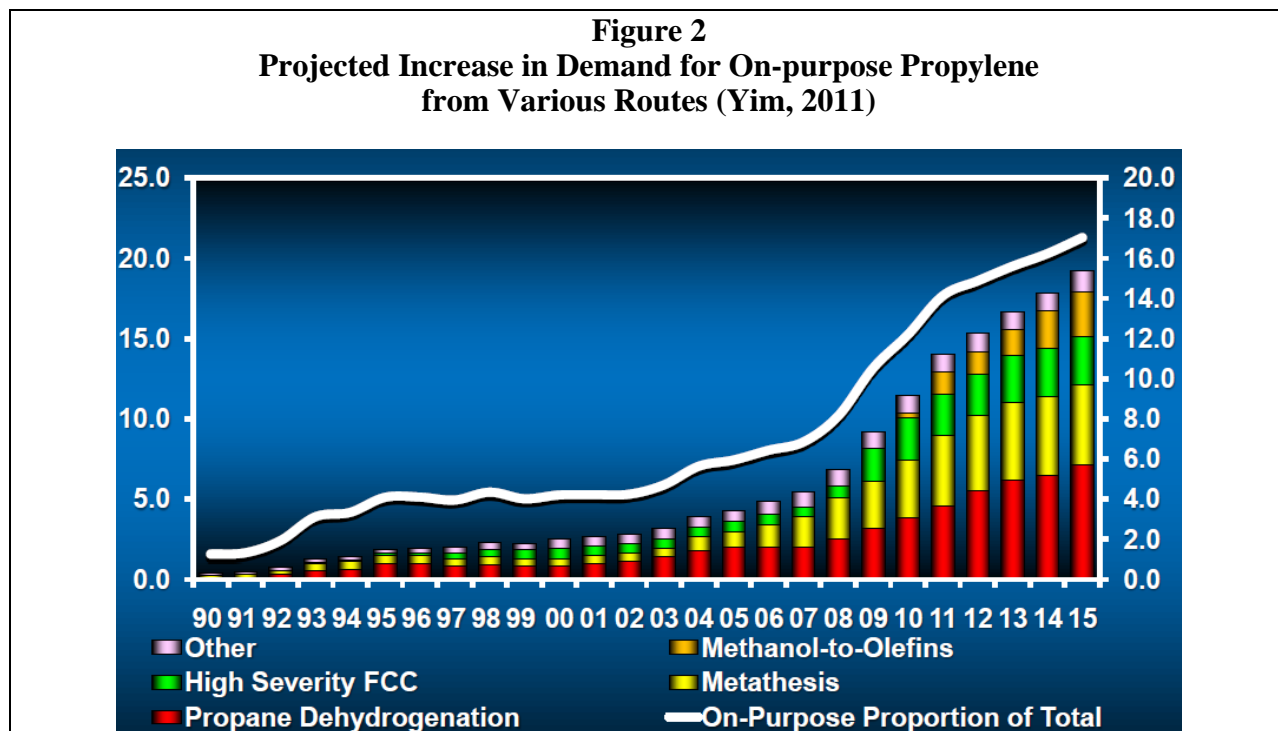
This newly updated report covers some very important commercial topics for executives and technologists, critically important to business planning and decision making over the next few years. The topics examined include:

- 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.

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 CO₂ 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 C₃= production technologies are the economic solution/choice (see Figure 2). However, this has been examined to determine whether incremental costs to address the C₂= vs. C₃= imbalance, are the only advantages.



To date, the FCC approach (while very successful for C₃=) has not solved the economical recovery of C₂=. 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).

- 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.

UNCONVENTIONAL CATALYTIC OLEFINS PRODUCTION: COMMERCIAL VISION AND BREAKOUT?

Table of Contents

I.	INTRODUCTION/BACKGROUND	1
	A. INTRODUCTION.....	1
	B. BACKGROUND.....	1
	C. THE NEED FOR THE STUDY	5
	D. THE STUDY TEAM	6
	E. GLOSSARY OF TERMS AND ABBREVIATIONS	7
	F. REFERENCES.....	8
II.	EXECUTIVE SUMMARY.....	11
	A. STATUS QUO.....	12
	1. Steam Cracking.....	13
	a. Coking in Crackers	15
	2. FCC.....	17
	3. On-Purpose Propylene Production	20
	B. BEYOND THE STATUS QUO.....	21
	C. THE VISION AND BREAKOUT?	23
	1. Feedstock Pre-treatment	24
	2. Catalysts and Reactor System.....	25
	a. Catalysts for Olefin Production	25
	b. Catalytic Olefin Production Using Radial Flow Reactors	26
	c. Catalytic Olefin Production Using a Fluidized Bed Reactor.....	26
	3. Separation	27
	D. CONCLUSIONS AND RECOMMENDATIONS	28
	E. REFERENCES.....	32
III.	COMMERCIAL LANDSCAPE	33
	A. FEEDSTOCK UTILIZATION	34
	1. Regional Feedstock Trends	35

a. Middle East	35
b. North America.....	36
c. Europe	39
d. China	39
B. OLEFINS SUPPLY/DEMAND, REGIONAL UTILIZATION	41
C. PROJECTS: COMMERCIAL AND PLANNED	44
D. ENGINEERING AND FINANCIAL HURDLES	48
E. REFERENCES.....	51
IV. BENCHMARKING EXISTING OLEFINS PRODUCTION.....	53
A. OLEFINS CRACKERS	53
1. Overview and Economic Pinch Points.....	53
2. Licensed Cracking Technology.....	55
a. Lummus Process	56
b. Shaw Stone and Webster (SSW) – Ultra Selective Conversion (USC).....	59
3. Coking in Crackers.....	63
4. Issues/Challenges.....	66
B. FCC OLEFINS PRODUCTION OVERVIEW.....	67
1. Overview and Economic Pinch Points.....	68
2. Licensed FCC Technology.....	70
a. KBR/ExxonMobil Orthoflow FCC	71
b. Technip (SSW, IFP/Axens) R2R	74
3. Issues/Challenges	78
C. ON-PURPOSE PROPYLENE PRODUCTION	80
1. UOP Oleflex Process.....	81
2. CB&I/Lummus Olefins Conversion Technology (OCT).....	83
3. UOP Oleflex vs. Other Processes.....	85
D. REFERENCES.....	86
V. NEW OLEFINS PRODUCTION	89
A. BEYOND THE STATUS QUO.....	89
B. PROFILES/ECONOMICS ON KEY PILOT & COMMERCIAL PROCESSES.....	91
1. SK - KBR Advanced Catalytic Olefins (ACO) Process	91
a. Key milestones.....	91

b.	Commercialization status	91
c.	Technical process overview	93
d.	Economics	94
e.	Summary	95
2.	ExxonMobil PCC (Propylene Catalytic Conversion) Process	95
a.	Key milestones	96
b.	Commercialization status	96
c.	Technical process overview	97
d.	Summary	98
3.	DICP Catalytic DMTO (Dimethyl Ether/Methanol-to-Olefins)	98
a.	Key milestones	98
b.	Commercialization status	98
c.	Technical process overview	100
d.	Economics	101
e.	Summary	101
4.	UOP/Total MTO (Methanol-to-Olefins)	102
a.	Key milestones	102
b.	Commercialization status	103
c.	Technical process overview	104
d.	Economics	105
e.	Summary	106
5.	Lurgi MTP (Methanol-to-Propylene)	106
a.	Key milestones	106
b.	Commercialization status	107
c.	Technical process overview	108
d.	Economics	109
e.	Summary	110
6.	Sinopec DCC (Deep Catalytic Cracking) Process	110
a.	Key milestones	110
b.	Commercialization status	111
c.	Technical process overview	112
d.	Summary	114
7.	Sinopec CPP (Catalytic Pyrolysis Process)	114

a.	Key milestones	115
b.	Commercialization status	115
c.	Technical process overview	116
d.	Economics	118
e.	Summary	119
8.	Aither Chemical Process	119
a.	Key milestones	119
b.	Commercialization status	120
c.	Technical process overview	120
C.	SEPARATION ADVANCES	121
1.	Adsorbents.....	121
a.	Novel synthetic zeolites	121
b.	Separation processes using adsorbents.....	122
i.	UOP MaxEne™ Process.....	122
ii.	Xebec	128
2.	Novel Membranes	128
a.	Conventional polymeric membranes.....	128
b.	Membranes with transition metal salts.....	128
c.	Hybrid systems of membrane and distillation.....	129
i.	Energy Research Centre for the Netherlands (ECN) Case Studies	129
D.	PROFILES ON R&D PROCESSES	132
1.	Oxidative Coupling of Methane (OCM)	132
2.	Selective Oligomerization	136
E.	References	138
VI.	ADVANCED ENGINEERING DESIGNS	141
A.	FEED PRE-TREATMENT AND PRODUCT SEPARATION.....	141
1.	Adsorption Technology.....	141
2.	Catalytic Distillation	144
3.	Membrane Reactors	147
B.	REACTOR DESIGN SELECTION.....	148
1.	General Introduction to Reactor Selection.....	148
2.	Adiabatic Reactors	149
3.	Multifunctional Reactors.....	152

a. Intra-reactor oxidative reheat	153
C. INFLUENCE OF CATALYST REQUIREMENTS.....	154
1. Meso-pPorous Catalysts.....	155
2. Thin Layer Catalysts	157
3. Attrition Resistant Catalyst	157
4. Micro-Engineered Catalyst systems.....	158
D. PROCESS INTENSIFICATION	159
E. THERMODYNAMIC DESIGN CONSIDERATIONS	161
F. REVIEW AND SUMMARY	162
G. REFERENCES.....	163
VII. THE VISION AND BREAKOUT?.....	167
A. FEEDSTOCK PRE-TREATMENT	168
B. CATALYSTS AND REACTOR SYSTEM.....	170
1. Catalysts for Olefin Production.....	170
2. Catalyst Manufacturing.....	171
3. Catalyst Deactivation	172
4. Catalytic Olefin Production Using Radial Flow Reactors	172
5. Catalytic Olefin Production Using a Fluidized Bed Reactor	173
C. SEPARATION.....	174
D. SUMMARY	174
E. REFERENCES.....	175
VIII. CONCLUSIONS AND RECOMMENDATIONS.....	179
APPENDIX	183

FIGURES

Figure I-B-1	Typical values of specific CO ₂ emissions from thermal cracking furnaces as a function of feedstock	3
Figure I-C-1	Projected increase in demand for on-purpose propylene from various routes	5
Figure II-A-1	Integrated olefin production train.....	13
Figure II-A-2	Typical ISBL installed cost for steam cracking	14
Figure II-A-3	Projected increase in demand for on-purpose propylene from various routes	20
Figure II-C-1	Conceptional catalytic olefin production process steps	24

Figure II-C-2	Conceptional catalytic olefin production process steps	26
Figure II-C-3	Catalytic Distillation reactor principles	27
Figure II-D-1	Concept for catalytic production of olefins – design approaches	28
Figure III-A-1	Average 2010 steam cracker feedstock slates	35
Figure III-A-2	U.S. conventional gas overview	37
Figure III-A-3	U.S. NGL production from gas processing, MMBPD	38
Figure III-A-4	North American ethane production	38
Figure III-B-1	Development of global ethylene capacity by region	42
Figure III-D-1	Integrated olefin production train	50
Figure IV-A-1	Lummus-SRT Cracking™ Flow Scheme	54
Figure IV-A-2	Typical ISBL installed cost	55
Figure IV-A-3	SRT cracking heater	56
Figure IV-A-4	Twin-cell configuration	59
Figure IV-A-5	ARS block flow diagram	60
Figure IV-A-6	Existing and planned CAMOL furnace installations with level of feedstock contamination, pre-CAMOL operating temperature, and furnace capacity	65
Figure IV-B-1	Orthoflow FCC converter	72
Figure IV-B-2	Vapor recovery unit	73
Figure IV-B-3	SSW IFP RFCC unit process diagram	75
Figure IV-B-4	Side-by-side regenerator RFCC revamp design	76
Figure IV-C-1	Projected increase in demand for on-purpose propylene from various routes	80
Figure IV-C-2	C ₃ Oleflex plant	81
Figure IV-C-3	Olefin process flow	82
Figure IV-C-4	Olefins Conversion Technology flow diagram	83
Figure V-B-1	ACO commercial demonstration unit, Ulsan, South Korea	92
Figure V-B-2	LSR naphtha cracking yields	92
Figure V-B-3	ACO™ Reactor System	93
Figure V-B-4	Typical ACO olefin recovery	94
Figure V-B-5	Steam cracker vs. ACO cost of production (COP)	95
Figure V-B-6	PCC Integration with FCC	96
Figure V-B-7	Large 1.5 bbl/d riser pilot plant used in the development of the PCC Process	96

Figure V-B-8	Reactor / regenerator scale-up.....	97
Figure V-B-9	Catalytic cracking process for propylene.....	97
Figure V-B-10	DMTO-II demonstration unit diagram.....	99
Figure V-B-11	Shenhua Baotou 600 KTA DMTO project	99
Figure V-B-12	Typical DMTO conversion/selectivity results	100
Figure V-B-13	Cost: DMTO & naphtha cracking	101
Figure V-B-14	UOP MTO Process diagram.....	102
Figure V-B-15	MTO demo unit.....	103
Figure V-B-16	Advanced MTO process unit by Total Petrochemicals in Feluy, Belgium.....	103
Figure V-B-17	MTO UOP/HYDRO MTO Process	104
Figure V-B-18	MTO yields with C ₄ ⁺ olefin recycle.....	105
Figure V-B-19	MTO selection factor	106
Figure V-B-20	Lurgi MTP in China.....	107
Figure V-B-21	Scale-up history.....	108
Figure V-B-22	MTP – simplified process flow diagram.....	109
Figure V-B-23	DCC Thai Petrochemical Industries.....	111
Figure V-B-24	Block flow diagram of a typical DCC unit for olefins production and recovery.....	113
Figure V-B-25	CPP commercial prototype	115
Figure V-B-26	CPP pyrolysis gas purification and separation project.....	117
Figure V-B-27	Typical yields range for ethylene and propylene for RIPP/SSW DCC and CPP processes.....	117
Figure V-B-28	The scheme of crude to petrochemicals	118
Figure V-C-1	UOP MaxEne Process	123
Figure V-C-2	Refinery complex with MaxEne constant full range naphtha feed rate - Case study #1	124
Figure V-C-3	Refinery complex with MaxEne constant reformer feedrate	125
Figure V-C-4	The MaxEne Process Effect, case study #1 – refinery GM comparison	127
Figure V-C-5	The MaxEne Process Effect, case study #2 – refinery GM comparison	127
Figure V-C-6	Hybrid configuration in ethylene/ethane separation – membrane in upstream	130
Figure V-C-7	Operation cost, only electricity and cooling water.....	130

Figure V-C-8	Payback period of investment made in a membrane system to debottleneck a C ₂ -splitter vs ethylene permeance.....	131
Figure V-D-1	Elemental compositions of OCM catalysts with YC ₂ ≥ 25% reported in the literature	132
Figure V-D-2	Flowsheet for the Oxidative Coupling of Methane Process.....	134
Figure V-D-3	Simplified flowsheet of the Synfuel GTE (gas-to-ethylene) process.....	136
Figure VI-A-1	Pre-treating of naphtha by adsorption	142
Figure VI-A-2	Optimization of naphtha utilization	142
Figure VI-A-3	Cracking yields from paraffin oil.....	143
Figure VI-A-4	Fixed-bed adsorption system.....	143
Figure VI-A-5	UOP's MaxEne Process	144
Figure VI-A-6	Catalytic Distillation reactor principles	145
Figure VI-A-7	Conventional olefin purification	146
Figure VI-A-8	Front-end CD-Hydro©.....	147
Figure VI-A-9	Catalytic membrane reactor	147
Figure VI-B-1	Development history of fixed-bed reactors.....	149
Figure VI-B-2	Catofin reactor system CBI-Lummus technology.....	150
Figure VI-B-3	Styrene reactors historical development	151
Figure VI-B-4	Uhde STAR process.....	151
Figure VI-B-5	Catalytic cycle for olefin production with oxidative reheat.....	153
Figure VI-B-6	Radial reactors for olefin production	154
Figure VI-C-1	Ceramic foam versus TUD-1	156
Figure VI-C-2	Physical properties of TUD-1	156
Figure VI-C-3	Manufacturing of thin film catalyst.....	157
Figure VI-C-4	Thin film catalyst	157
Figure VI-C-5	Attrition resistant VPO catalyst for butane oxidation	158
Figure VI-C-6	Micro-engineered catalyst technology	159
Figure VI-D-1	Catalyst particle in a reacting medium.....	160
Figure VI-E-1	ΔG kJ/mol for converting hexane and octane to olefins	161
Figure VII-1	Conceptional catalytic olefin production process steps	168
Figure VII-A-1	Synthesis of TUD-C and TUD-M	170
Figure VII-B-1	Heater with catalytic burners	173

Figure VII-B-2	Conceptional catalytic olefin production process steps using a fluidized bed reactor.....	173
Figure VIII-1	Concept for catalytic production of olefins – design approaches.....	179

TABLES

Table I-B-1	Top Ethylene Producers and Refiners with Largest FCC Capacity.....	2
Table I-B-2	World Production for Ethylene and Propylene: 2010.....	2
Table I-B-3	World End-Use for Ethylene and Propylene: 2010.....	2
Table II-A-1	Ethylene Production Cost Components	14
Table II-A-2	CAMOL Coatings Key Catalytic Properties and Targeted Feedstocks.....	15
Table II-A-3	CAMOL Technology Status in Year-4 of Commercial Furnace Trials (at March 2010) – Crystallized and Projected Achievable Benefits	16
Table II-A-4	Investment Cost of Incremental Propylene	19
Table II-A-5	Comparative Economics – Propane Dehydrogenation vs. OCT Process.....	21
Table II-C-1	New Zeolite Catalyst Yields	25
Table III-B-1	Regional Ethylene Capacity (as of Jan. 1, 2012).....	41
Table III-B-2	Largest Ethylene Producers (as of Jan. 1, 2012).....	42
Table III-B-3	U.S. Ethylene Expansions Based on Shale Gas.....	43
Table III-B-4	Ethylene Production Feedstock: 2010.....	43
Table III-B-5	Propylene Production by Source: 2010.....	44
Table III-C-1	Planned Ethylene Projects.....	45
Table III-C-2	Recent and Ongoing PDH Projects	47
Table III-C-3	Alternative Planned Propylene Capacity	48
Table IV-A-1	Typical Range of Operating Parameters	58
Table IV-A-2	Ethylene Production Cost Components	61
Table IV-A-3	Typical Distribution of Products from Different Feedstock	62
Table IV-A-4	Generic Economics: Steam Cracking of Ethane	62
Table IV-A-5	Generic Economics: Steam Cracking of Naphtha.....	63
Table IV-A-6	CAMOL Coatings Key Catalytic Properties and Targeted Feedstocks.....	64

Table IV-A-7	CAMOL Technology Status in Year-4 of Commercial Furnace Trials (at March 2010) – Crystallized and Projected Achievable Benefits	65
Table IV-B-1	Typical 25,000 BPD Gas Oil and Resid FCC Operations with and without ZSM-5 Compared to DCC	69
Table IV-B-2	Heavy-Feed Processing Capabilities of Various Heat Rejection Systems	77
Table IV-B-3	Investment Cost of Incremental Propylene	79
Table IV-C-1	Utility, Feed, and Product Valuations for Economic Calculations.....	82
Table IV-C-2	Cost for Producing 350,000 MTA of Polymer-Grade Propylene Using the Oleflex Process.....	83
Table IV-C-3	Comparative Economics – Propane Dehydrogenation vs. OCT Process.....	84
Table V-B-1	Comparison of the Product Stream Comparison: Naphtha vs DMTO	101
Table V-B-2	MTP Economics.....	110
Table V-B-3	Licensed DCC Units	112
Table V-B-4	Typical Operating Parameters for a DCC Unit Compared with FCC and Steam Cracking Units.....	113
Table V-B-5	DCC Light Olefin Yields	114
Table V-B-6	CPP - Main Operating Parameters	116
Table V-B-7	CPP - Product Distribution and Olefin Yields	116
Table V-B-8	Key Economic Data for a CPP Integrated Olefins Plant.....	119
Table V-C-1	The MaxEne Process Effect Case Study #1 – Refinery Balance.....	124
Table V-C-2	The MaxEne Process Effect Case Study #1 – Steam Cracker Balance.....	125
Table V-C-3	The MaxEne Process Effect Case Study #2 - Refinery Balance.....	126
Table V-C-4	The MaxEne Process Effect Case Study #2 - Steam Cracker Balance	126
Table V-D-1	OCM Process Economics.....	134
Table V-D-2	Global Oil Majors and Number of Patents in Converting Methane to Ethylene	135
Table VI-A-1	Commercial CD Applications	145
Table VII-B-1	New Zeolite Catalyst Yields	171

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

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.

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 **“Unconventional Catalytic Olefins Production: Commercial Vision and Breakout?”** completed January 2013, as follows:

_____ **Unconventional Catalytic Olefins Production: Commercial Vision and Breakout?**
 for \$22,000

_____ 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 a member of TCGR's **Catalytic Advances Program (CAP)** 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.**

Signature: _____ Date: _____

Name: _____ Title: _____

Company: _____

Billing Address: _____

Shipping Address (no P.O. Boxes): _____

Express delivery services will not deliver to P.O. Boxes

City: _____ State/Country: _____

Zip/Postal Code: _____ Phone: _____

E-mail: _____ Fax: _____

This report and our study findings are sold for the exclusive use of the client companies and their employees only. No other use, duplication, or publication of this report or any part contained herein is permitted without the expressed written consent of The Catalyst Group Resources.