Prospectus

Propylene Technology: The Next Generation

Nexant

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Propylene Technology: The Next Generation

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Nexant

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Section 1 Introduction

1.1 OVERVIEW

Nexant, a leading, global provider of consulting services to the energy industry, was established on January 1, 2000. Originally formed from a core group of approximately 130 professionals drawn from Bechtel's Technology and Consulting Group, the company has since grown organically and through acquisitions and now totals over 350. As an independent company with a number of shareholders, Nexant provides impartial advice to clients in the energy sector.

Nexant's global headquarters are in San Francisco. The company provides a range of services to the energy industries, as detailed in our literature and on our website at www.nexant.com. For more information on the *ChemSystems* division, please visit www.chemsystems.com.

The foundations of Nexant's Energy and Chemicals Consulting (E&CC) Division are based on more than 20 years of experience in the oil and gas industries as part of Bechtel's consulting business. In 2001, Nexant acquired the ChemSystems operation from IBM. Now fully integrated with the Nexant E&CC Division, ChemSystems has been providing management consulting services to the petroleum and chemical industry since 1964. Our consolidated expertise and experience is unrivalled by any other specialist consulting firm in the industry.

Chem Systems has a forty-four year history as an independent, industry-expert consulting firm providing technical, commercial and valuation consulting for the petroleum, refining, and chemical industries. In 1998, Chem Systems was acquired by IBM, and subsequently in 2001, Chem Systems was acquired by Nexant, Inc. Nexant maintains Chem Systems' (now ChemSystems) intellectual capital and consultant continuity, and continues ChemSystems' business activity and brand name within Nexant's Energy and Chemical Consulting Division, in which we continue to perform the types of work that we have throughout ChemSystems' history. Thus, analysis of new technology developments is one of our core activities.

Propylene is one of the key "building block" petrochemicals used as feedstock for a variety of polymers and chemical intermediates. Major propylene derivatives include polypropylene, acrylonitrile, propylene oxide, cumene/phenol, oxo alcohols, acrylic acid, isopropyl alcohol, oligomers, and other miscellaneous intermediates. These are mostly used, in turn, in a wide range of end-use applications including automotive, construction, consumer durables and non-durables, packaging and electronics.

In 2003, Nexant analyzed emerging technology for the on-purpose production of propylene in our report, *Technology Developments in Propylene and Propylene Derivatives*. This report was motivated by the expected shortfall in future conventional propylene production capacity and the emergence of on-purpose production technologies intended to meet that demand. Several of these technologies have been commercialized, such as propane dehydrogenation; metathesis and enhanced recovery from refinery streams, and several more are very promising.

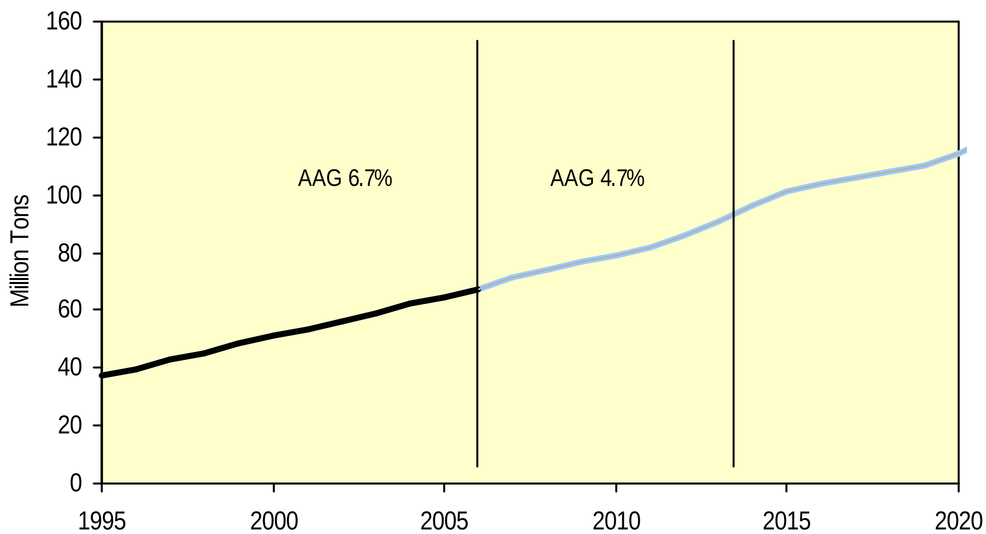
Since then, additional new technologies and feedstocks, as well as improvements to the emerging technologies we discussed in our previous report, have appeared, or are in development. These may significantly change the technology and regional production landscape.

This prospectus describes the background of why emerging propylene technology is an important and timely issue, the scope of our analysis, and the approach we used in the study. We also detail our experience and qualifications to perform the study, and how you may subscribe.

1.2 BACKGROUND

As shown in Figure 1.1, global propylene demand grew from 37.2 million tons in 1995 to approximately 52 million tons in 2000, corresponding to an average annual growth of 5.5 percent. Demand grew at an average rate of 4.6 percent per year from 2000 to 2006, reaching almost 67 million tons.

Figure 1.1 Global Propylene Demand



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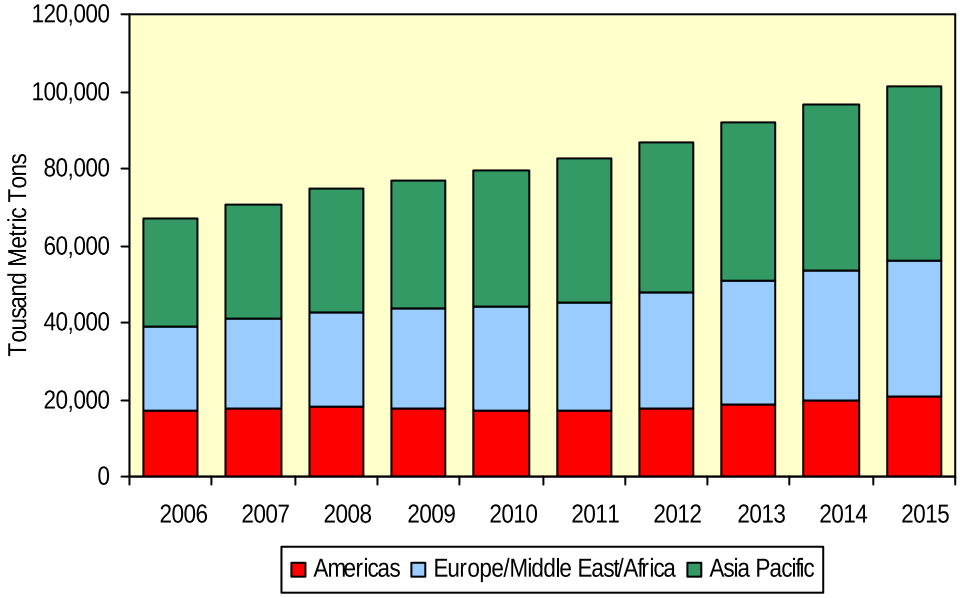
Demand for propylene is expected to grow at almost 5 percent annually for the period 2007-2015, to more than 100 million tons by 2015. This increase will be driven by the demand for derivatives, especially polypropylene and propylene oxide, the demand for which is growing at the rate of 5.5 percent and 4.3 percent, respectively, for the same time period. Propylene consumption by region is shown in Figure 1.2.

Figure 1.2 Global Propylene Consumption Trends by Region



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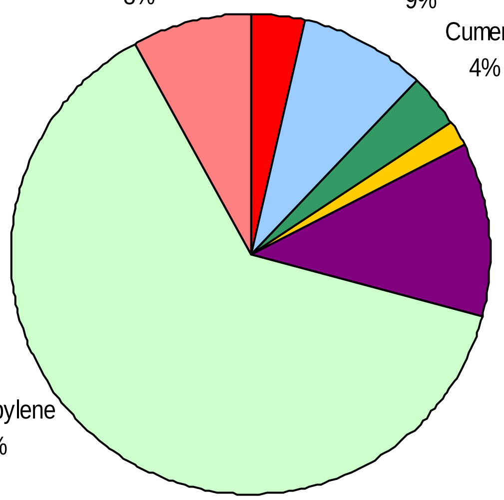
Propylene demand is expected to grow more quickly than supply from traditional sources. Traditional propylene supply/demand conditions and pricing are strongly dependent on refinery production and the supply/demand balance, operating rates and feedstock slates in the ethylene industry. Globally, more than 25 percent of the new crackers started up in the 2003-2007 timeframe are based on ethane and, therefore, will produce little propylene. Moreover, steam cracker expansions and/or additions cannot keep in pace with propylene demand growth. Increase in refinery propylene production has also slowed down due to environmental concerns, further tightening propylene supply.

Propylene is produced commercially on purpose by dehydrogenation of propane, but in most situations this is an expensive route and usually generally requires favorable feedstock pricing to be competitive. Only recently has the propylene production from propane dehydrogenation become a more economically feasible option.

The amount of propylene produced by propane dehydrogenation is still small compared to the traditional sources.

Propylene is used in a number of major derivatives, as shown in Figure 1.3, with polypropylene by far the largest end-use.

Figure 1.3 Global Propylene Demand by Derivative



Based on demand growth trends for the key propylene derivatives and limited supplies, the potentially higher prices of propylene that might result could restrict growth and impact on cross elasticity of demand in applications in which substitution is possible, e.g., polypropylene versus polyethylene, polystyrene, and ABS.

Expanded or converted sources of propylene will have to be found, whether as an on-purpose supply or from redirection of existing capacity. Depending on the demand and alternative value for ethylene versus propylene, it may be economically advantageous to either produce more propylene at the expense of ethylene or produce propylene by alternative means.

The primary sources of propylene have been as a byproduct of ethylene production in steam crackers and from refinery FCC streams. The now commercialized alternative technology of propane dehydrogenation is only economical under certain conditions in certain areas of the world. As propylene demand continues to outpace ethylene demand, there is increasing interest and need in finding or developing alternative sources of propylene without adversely affecting ethylene availability. Conversion to higher activity FCC catalysts, a proven approach to increase propylene production, is not always the best solution due to competing economic and technical drivers to produce motor gasoline and number 2 fuels, FCC's primary products. New technologies, using an expanding range of feedstocks, may change conventional propylene supply dynamics and economics, as well as the competitive regional supply balance.

Major regions will likely respond differently to the tightening propylene supply. While North America and Europe have a slow demand growth, Asia and the Middle East will experience more severe shortages in propylene. In Asia, this is driven by China's large and growing consumption. This rapid demand growth along with increases in price has resulted in a large amount of investment in Asia with approximately 41 percent of new propylene resulting from alternative sources. A significant amount of the new crackers in the Middle East are ethane based which will go a long way to satisfying the growth in ethylene, but the region's investment in naphtha and distillate crackers is limited, which will limit the amount of propylene produced. Naphtha crackers currently provide 70 percent of Asia's propylene supply. This has propylene producers exploring other technologies to assure there is sufficient propylene supply.

Nexant's new report, ***Propylene Technology: The Next Generation***, examines and compares the process technologies and economics of the commercially available and developing technologies for the production of propylene alone or as a co-product. The report focuses on the economics of alternate process and feedstock routes to propylene, how they compare to conventional routes, and how competitive they are. These routes include the conventional processes and feedstocks that have been practiced for years:

- Conventional steam cracking
- Production and recovery from refinery streams
  - High Propylene Catalytic Cracking
  - Deep Catalytic Cracking (DCC)
  - Catalytic Cracking (conventional)
- Propane dehydrogenation

The conventional technologies are reviewed and evaluated in operating modes that maximize propylene production. For instance, conventional steam cracking is discussed and production economics evaluated with an emphasis on cracking severities for the various feedstocks that favor the production of propylene over ethylene.

These conventional propylene technologies are compared to the newer and developing technologies for propylene production, some which have been proven commercially, and others that are near commercialization as well as those in the development stages. Nexant examines and analyzes newer developments in alternate technology and feedstock sources, and those technologies that are designed to either produce propylene exclusively or increase propylene yields from conventional sources.

The evaluation of newer commercial technology includes:

- Olefin Metathesis
- Catalytic Pyrolysis
- High Severity (High Propylene) Fluid Catalytic Cracking
- Natural Gas Based Processes
  - Methanol to Olefins (MTO)
  - Methanol to Propylene (MTP)

- Olefin Interconversion

The evaluation of these technologies includes existing technology developers as well as those new to the specific technology. For instance, for Methanol to Propylene, Nexant includes evaluations of the latest technology from existing technology holders ExxonMobil, UOP/Hydro, and Lurgi, as well as a more recent entrant, Dalian Institute of Chemical Physics (DICP).

There have been several recent technology developments that may prove to be interesting propylene production options:

- Sinopec Olefin Catalytic Cracking (OCC)
- Sinopec Catalytic Pyrolysis Cracking (CPP)
- ExxonMobil Propylene Catalytic Cracking (PCC)
- Asahi Kasei Chemical Omega Process

Nexant also investigates and evaluates alternate feedstocks for propylene production. The use of stranded (or remote), low cost natural gas has already been proposed via MTP. Coal is another alternative, in those countries with plentiful reserves, for MTP as well. Nexant also examines the use of biomass via promising technologies. Thus, alternate feedstock technologies that are investigated include:

- Natural gas
  - Natural gas to propylene (via natural gas to synthesis gas to MTP)
- Coal
  - Coal to propylene (coal to synthesis gas via gasification, and then to MTP)
- Biomass

  The practical use of biomass as a raw material for fuels production is becoming a growing reality. Chemicals production from biomass is also gaining interest and propylene production has several viable options. Nexant investigated potentially practical avenues for propylene production such as:

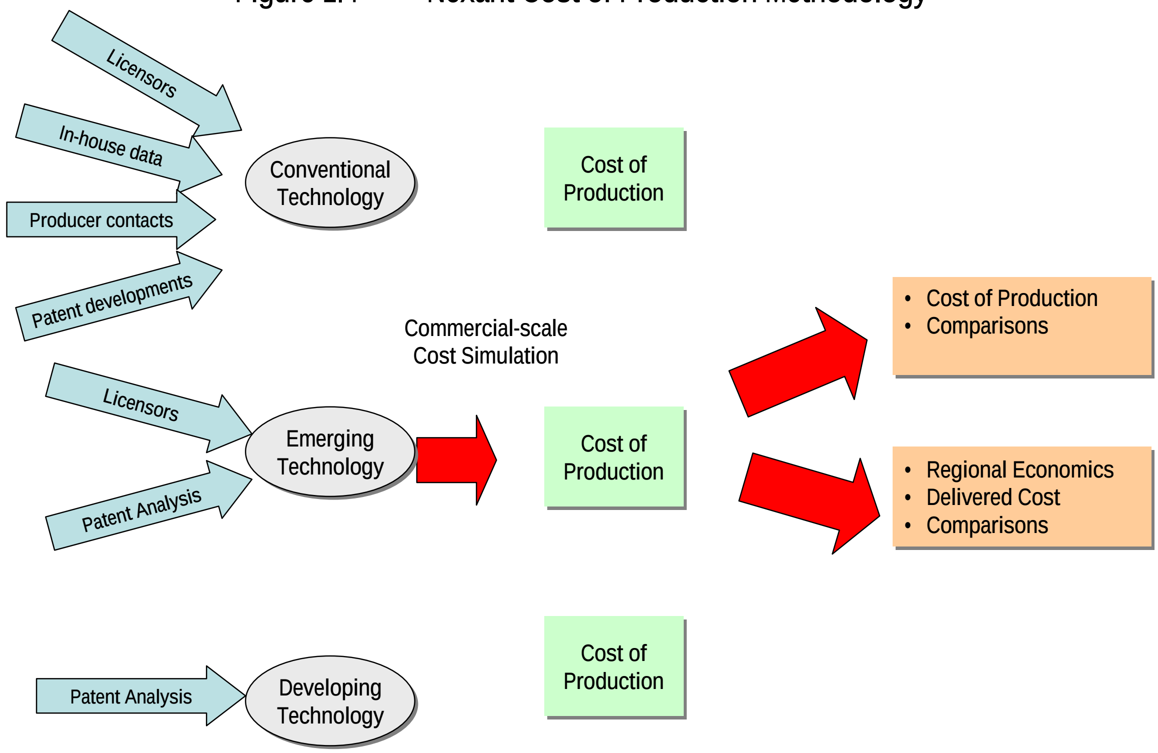
  - Hydrocracking natural fats and oils (triglycerides) and isomerization to produce biodiesel with propane co-product. The propane can be recovered and dehydrogenated to propylene. This is just one example of potential biomass routes that will be investigated.
  - Gasifying biomass, such as wood, to synthesis gas and then producing methanol and propylene via MTP:
  - Switchgrass fermentation to ethanol followed by dehydration to ethylene and metathesis to propylene
  - Enhanced FCC using soybean oil feedstock

– Ethanol from corn followed by dehydration to ethylene and metathesis to propylene

For these and other interesting alternative technologies discovered during our research, Nexant developed and compared costs of production on a regional basis, taking into account regional feedstock and conversion costs, regional construction costs, and other factors that can differentiate production dynamics. Major regions evaluated include the United States, Western Europe, Southeast Asia, Northeast Asia (China), and the Middle East.

Nexant used its highly regarded methodology for cost of production analysis and comparison on a consistent basis. This includes inputs of data from sources such as technology holders, producers and patent disclosures, and our own analysis and simulation of the data to arrive at commercial-scale cost evaluations. This methodology is summarized in Figure 1.4.

Figure 1.4 Nexant Cost of Production Methodology



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Nexant's overall objective for the ***Propylene Technology: The Next Generation*** study is to assess and evaluate the important technology issues that will affect the future availability and supply of propylene. The study provides an in-depth quantitative and qualitative analysis of the various new and developing technologies for the production of propylene, from both conventional and non-conventional feedstocks. An important part of this assessment and evaluation is a discussion of the commercial issues including projected impact of these technologies on regional propylene demand, supply, and trade.

The report analyzes the major commercial and developing propylene technologies, including but not limited to:

- **Steam Cracking**

  Propylene is the primary ethylene co-product from a steam cracker. Two variables affect the distribution of co-products: choice of feedstock and severity of operation. Under a market-limited ethylene production scenario, operators could choose the feedstock that minimizes the production of ethylene by resorting to more naphthenic naphtha and gas oil feedstocks.

- **Recovery from Refinery Streams and High Severity FCC**

  Propylene is produced as a dilute stream in propane from the three main refinery processes, fluid catalytic cracking (FCC), visbreaking/thermal cracking, and coking. The propane/propylene proportions vary considerably depending on the process, feedstock, operating conditions and, for FCC, catalyst.

  Refineries in developing regions such as East Asia and Latin America have varying degrees of complexity but on average produce much less FCC propylene. Economic development in these regions and trends towards use of gasoline fuels will justify refinery expansions and greater refinery conversion, producing offgas propylene. Additionally, in both developing and developed regions, including North America, there are a number of refineries that do not currently recover propylene from FCC offgas. In this case, higher propylene prices might support investment in new propylene concentration facilities. The increase in FCC-sourced propylene is viewed as a major likely source of future propylene demand.

- **Propane Dehydrogenation**

  Propane dehydrogenation technology is readily available from a number of licensors and is used commercially, especially where propylene is in short supply, e.g., in the Middle East and East Asia. The economics for this route are highly dependent on feedstock availability and cost. Nexant estimated and compared the cost of production economics in the various regions where feedstock availability makes this technology a viable alternative.

- **Olefin Metathesis**

  Metathesis involves the conversion of ethylene to propylene and, as such, the major commercial issue is the use of ethylene as a feedstock. Olefins metathesis can be added to steam crackers in order to boost propylene production via the cracking exchange reaction of ethylene and by-product mixed butylenes. This technology is available from various licensors.

  Variations on metathesis may include production of propylene from butene only and dimerization of ethylene to butene for reaction with additional ethylene for regions (such as the Middle East) where ethylene is the primary cracker product.

- **Deep Catalytic Cracking (DCC)**

  DCC utilizes fluid catalytic cracking principles combined with a proprietary catalyst, different operating conditions, and other enhancements to achieve its objective of producing the maximum light olefins from vacuum gas oil.

- **Catalytic Pyrolysis Process (CPP)**

  CPP is a modification of the deep catalytic cracking (DCC) process and can be adjusted to provide for a maximum output of either propylene or ethylene or an intermediate composition between these two modes. This is accomplished through a change in the operating conditions.

- **Methanol to Olefins (MTO)/Methanol to Propylene (MTP)**

  The availability of low cost methanol along with the rise in propylene demand makes the methanol-to-olefins (MTO) or methanol-to-propylene (MTP) processes viable. Low cost (advantaged) gas regions generally support ethane cracking rather than heavy liquids cracking, hence, such regions have ample supply of ethylene but insufficient propylene supply.

- **Olefin Interconversion**

  Olefin Interconversion is based on the catalytic cracking of C_4s and C_5s in a fixed or fluidized bed reactor. The process is compatible with ethylene crackers and FCCs and, unlike metathesis, does not consume ethylene.

- **Alternate Conventional Feedstocks**

  The MTO/MTP routes to propylene start with the production of methanol from synthesis gas. Though low cost remote natural gas is a probable source of the methanol, low cost coal in coal-rich regions is another viable and probable alternative.

- **Biomass**

  Biomass is being investigated for a wide range of chemicals and fuels production. One such possibility is the hydrocracking of natural fats and oils (triglycerides) and isomerization to produce biodiesel with propane co-product that can be converted to propylene. Nexant examined this and other potential uses of biomass, the economics for the production based on a wide range of feedstock and co-product price scenarios and the viability of feedstock on a regional basis.

The report includes a critical assessment of the main alternative on-purpose technologies, comprising a review of the technologies and licensors, commercial experience, and analysis of the competitive costs of production versus propylene at typical market prices and from conventional production.

The study includes technology, economic, and commercial evaluations:

Technology Evaluation – A detailed review and status of the various process routes including: patent review and analysis, technology holders and offerers, licensor package analysis and cost of production development for what would be considered representative of each technology, identification of the stage of process package commercial development with a listing of actual and announced projects.

Economic Evaluation – Cost of production estimates for typical estimated year average 2007 and projected 2015 conditions were developed for each of the developing technologies for comparison to conventional technology and to other developing technologies for propylene production. Costs are developed for the major producing regions, the United States, Western Europe, Middle East, Southeast Asia, and China, as well as for other locations more suited to the technology and/or feedstock, where applicable, such as for MTO and MTP (i.e., stranded gas location). A typical cost of production worksheet is shown in Table 2.1 and a theoretical comparison of production costs, such as for propylene-enhancing (or "add-on") technologies, is shown in Figure 2.1.

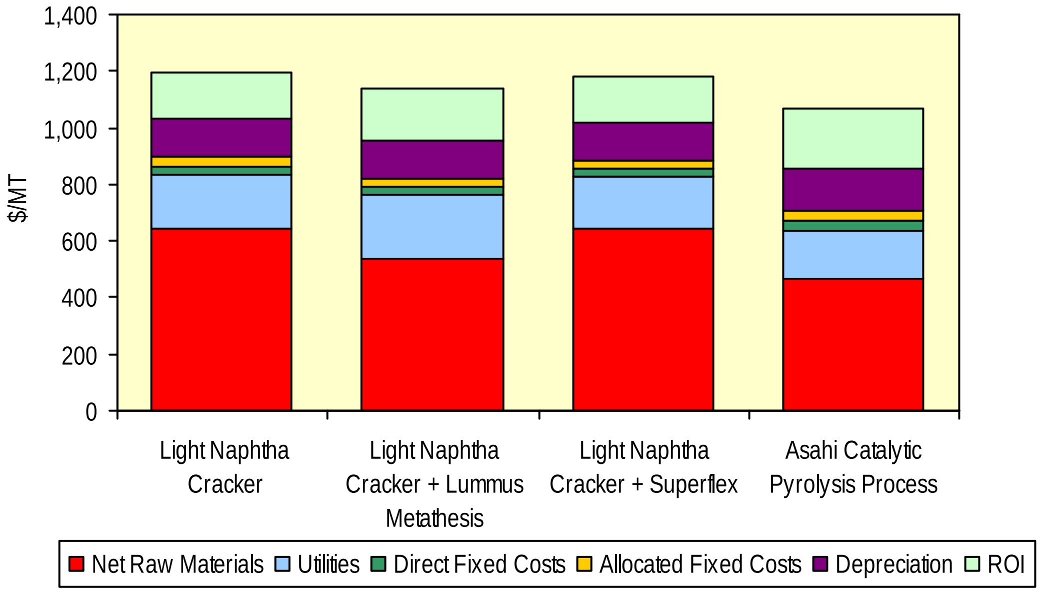
Table 2.1 Cost of Production Estimate for Propylene

Process: Recovery from Refinery Propylene, USGC location

Capacity	467	thousand tons/year	CAPITAL COSTS		
Operating Rate	90	percent	Battery Limits (ISBL)	56	$ million
Production	421	thousand tons/year	Offsites (OSBL)	28	$ million
Analysis Period: 2007.1			Total Fixed Invest	84	$ million

PRODUCTION COST SUMMARY	Quantity (per Ton)	Units	Price (US Dollars/unit)	Annual Cost (thousand $)	Unit Cost (US Dollars/Ton)
Raw Materials					
Refinery Propylene (75%)	1.010	Ton	863.67	366,890	872.30
Catalyst & Chemicals		-		4,859	11.55
Total Raw Materials Costs				371,749	883.86
Utilities					
Electricity	0.141	MWh	61.41	3,639	8.65
Low Pressure Steam (50 psig)	0.326	ton	23.85	3,270	7.77
Cooling Water	0.116	kton	29.39	1,428	3.40
Total Utility Costs				8,337	19.82
Total Variable Costs				380,086	903.68
Direct Fixed Costs					
Labor	10	people/year	45,893	459	1.09
Foreman	0	people/year	52,091	0	0.00
Supervision	1	people/year	62,858	63	0.15
Direct Overheads	45	% total salary cost		235	0.56
Maintenance	2.4	% ISBL		1,351	3.21
Total Direct Fixed Costs				2,108	5.01
Allocated Fixed Costs					
General Plant Overhead	60	% direct fixed cost		1,265	3.01
Local Tax/Insurance	2	% (ISBL+OSBL)		1,264	3.01
Total Allocated Fixed Costs				2,529	6.01
Technical Support/Royalty				0	0.00
Total Cash Cost				384,722	914.70

Figure 2.1 Ethylene Cost of Production with Enhanced Propylene Production
(U.S. dollars per metric ton, USGC, 2007)



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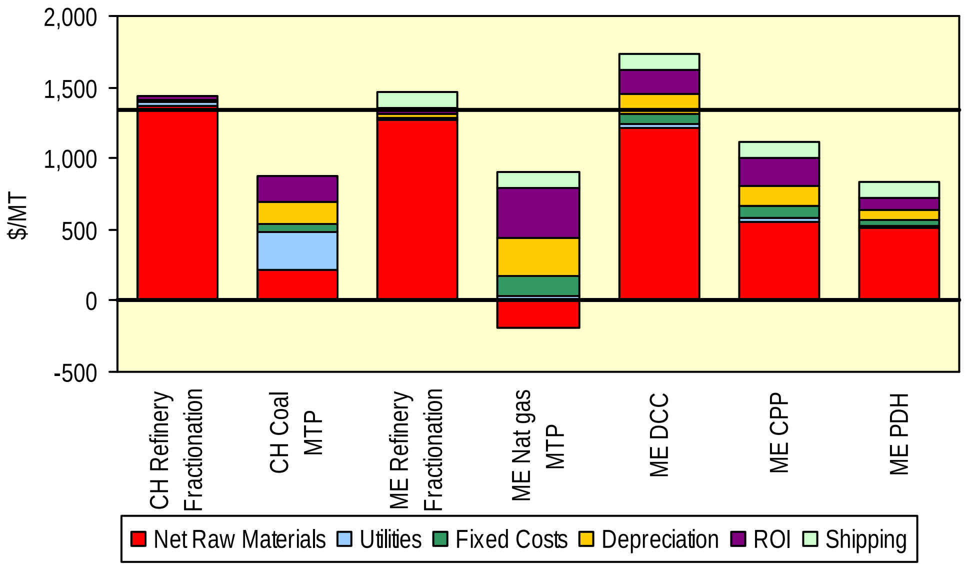
The economic comparisons are used to help develop regional production and competitive dynamics, which ultimately affect the regional propylene demand, especially in the case of alternate feedstocks. As a measure of regional competitiveness, delivered costs to the United States, Western Europe and China are estimated from each production region. An example of regional cost competitiveness is shown in Figure 2.2, with delivered costs, including tariffs and transportation costs, compared to regional domestic prices.

Figure 2.2 Delivered Cost of Propylene, China
(U.S. dollars per metric ton, 2007)



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Sensitivities are performed for important process variables, including the major feedstocks, and their effect on competitiveness versus the other feedstocks.

Because the comparison of propylene production costs is complicated by the economics for conventional steam cracking (for a naphtha cracker, ethylene is the principal product, with propylene as a co-product), Nexant uses novel comparison approaches. The economics for byproduct propylene production are not necessarily revealed using industry typical cost of production analysis. Propylene technology options, especially add-on options such as metathesis and olefin interconversion, will likely be linked to large-scale conventional steam crackers whose primary product is ethylene.

Commercial Outlook Overview – Nexant provides a forecast of propylene demand, production and trade, globally and by major region.

PROPYLENE TECHNOLOGY: THE NEXT GENERATION

Section

The evaluations of conventional technology are based on Nexant's in-house and published information regarding process technology, augmented by contacts with licensors, engineering contractors and other experts in the industry. The evaluations of developing technology are "built up" from a review of patents, public domain information, and discussions with the technology development companies and engineering contractors on a non-confidential information basis.

Nexant used its own proprietary, as well as commercial, state-of-the-art software tools to develop the technology and economic estimates. We employed well established and accepted chemical process industry engineering estimating tools and principles as used by major engineering contractors.

Additional aspects of our approach for this multi-client study are as follows:

- The economic evaluations are premised as typical regional costs of production based on capital costs that are appropriate for "factored estimates".
- The economic evaluations do not reflect specific site issues, but portray economics that are representative of the countries or regions as a whole.
- Commercial information and forecasts were developed from Nexant's extensive in-house databases, as augmented with selected regional fieldwork.
- Market projections were developed with the aid of Nexant's supply/demand computer modeling systems and databases

This project was managed and most of the work was carried out at Nexant's White Plains, NY office. Information and data for other regions was gathered as needed by consulting staff in Nexant's regional and representative offices in Bangkok, Beijing, Buenos Aires, Houston, London, Singapore, Seoul, and Tokyo.

The study was completed in February 2009.

Please visit www.chemsystems.com to authorize engagement of the study or return the following authorization form to one of Nexant's offices.

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