







# PROSPECTUS

From Diapers to Paints -Is Bio-Acrylic Acid on the Way?

# PROSPECTUS February 2013 From Diapers to Paints - Is Bio-Acrylic Acid on the Way?

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Acrylic acid and its esters are among the most versatile monomers for providing performance properties to a wide variety of polymers. The major application for acrylic acid is as a feedstock for acrylate esters which are used in applications that include surface coating, adhesives and sealants, textiles, plastic additives, and paper treatment. The global acrylic acid industry is growing at around four to five percent annually.

While a relatively large portion of acrylic acid is consumed for production of acrylate esters, a significant portion is upgraded (purified) into glacial acrylic acid and subsequently utilized for the production of polyacrylic acid or copolymers, which find applications in superabsorbents (for disposable diapers), detergent co-builders, dispersants, flocculants, and thickeners

Acrylic acid synthesis dates back to the mid-nineteenth century, but only came to prominence as a chemical intermediate in the 1930s when a reliable commercial synthesis (using Reppe chemistry) became available. A number of alternative processes for acrylic acid and acrylate production have been used or proposed over the years including acrylonitrile hydrolysis and the Reppe process. Figure 1.1 summarizes some of the commercial and developmental processes for acrylic acid production from petrochemicals.

Ongoing developments by major producers in petroleum-based acrylic acid include those by Arkema, BASF, and Novomer.

However, in light of global oil prices having reached unprecedented levels (hovering around \$100 dollars per barrel), as illustrated in Figure 1.2, many acrylic acid producers and/or licensors are trying to deviate from petroleum-based feedstocks.



Figure 1.1 Petrochemical-Based Routes to Acrylic Acid/Acrylates



#### Figure 1.2 Global Crude Oil Prices (Dollars per Barrel)

There is considerable research and development activity in the production of acrylic acid and acrylates from renewable resources using biotransformation techniques, as shown in Figure 1.3. Acrylic acid production emphasis has been placed on the use of sugar (from corn sugar or sugarcane) and glycerol as raw materials.

With the introduction of renewable feedstocks, the purification of acrylic acid has also been the subject of numerous improvements. Literature shows that techniques such as melt crystallization and liquid-liquid extraction have been studied for the purification of bio-acrylic acid rather than the conventional distillation and crystallization methods used for propylene-based acrylic acid.



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This report outlines, analyzes, and assesses acrylic acid technologies that would appear to be competitive or even economically advantaged relative to the petrochemical route. This report provides a comprehensive comparison of the technology, economics, and potential markets for acrylic acid produced via renewable sources versus petrochemical sources (including propylene, propane, and ethylene oxide), with an emphasis on examples such as the following:

- Bio-acrylic acid companies such as Arkema, Cargill, Celanese, Genomatica, Myriant, Nippon Shokubai, Novozymes, OPX Bio, and SGA Polymers are currently developing technologies that will produce acrylic acid from several bio-feedstocks such as glycerol and sugar
- Petrochemical-based acrylic acid companies such as Arkema, BASF, and Novomer are currently developing routes that can produce acrylic acid from different feedstocks such as β-popiolactone and propane

The report also provides an overview of the technology available for commodity acrylates and SAP and economic comparisons of the production of these from acrylic acid and glycerol-based acrylic acid.

This study provides the background to understand the fundamentals of bio-based acrylic acid and its derivatives.

The study was published in February, 2013. The cost of the study is US\$20,000.00 (twenty thousand U.S. dollars).

This study's objective is to assess the technical, commercial, and economic aspects of producing acrylic acid from renewable sources such as lactic acid, 3-hydroxypropionic acid (3-HP), or glycerol. The study also evaluates technical, commercial, and economic aspects of other developing routes that use non-biological paths such as the production from ethylene oxide and propane. Economic comparison of the bio and non-bio developing routes to the conventional propylene-based route is provided. The study overviews technology, commercial, and economic information on commodity acrylates and super absorbent polymers (SAP).

This report covers:

- Bio and non-bio based developing technologies for the production of acrylic acid
- New technological developments
- Description of the conventional routes to acrylic acid, commodity acrylates, and SAP currently in commercial operation
- Economics and cost competitiveness of bio and non-bio based routes, compared to the conventional route of acrylic acid
- Provide economics of butyl acrylate and SAP from bio-based acrylic acid, compared to conventional propylene-based acrylic acid
- Market outlook for acrylic acid and its main derivatives commodity acrylates and SAP

The study evaluates the competitiveness of current and emerging acrylic acid production routes with respect to a wide range of technical and economic assumptions, including: different feedstocks and location.

#### 2.1 TECHNOLOGY COVERAGE

Acrylic Acid routes considered in the study include:

- From lactic acid
- From 3-hydroxypropionic acid (3-HP)
- From fumaric acid
- From glycerol
- From ethylene oxide (via β-propiolactone intermediate)
- From propane
- From propylene (conventional route)
- From coal-based acetylene (Reppe process)

Acrylates routes considered in the study include:

• From esterification of acrylic acid (conventional route)

SAPs routes considered in the study include:

• From sodium polyacrylate

These process technologies are evaluated from technical, economic, and commercial perspectives. A review and assessment of representative process routes for each major technology is performed. In addition, the stage of process development is characterized.

Cost of production estimates are developed for the above acrylic acid, butyl acrylate, and SAP (from sodium polyacrylate) technologies in selected global locations. Sensitivities are performed on feedstock costs.

#### 2.2 FEEDSTOCK COVERAGE

The primary renewable feedstocks covered in the study are:

- Sugar
- Glycerol
- Biomass
- Lactic Acid
- Polyhydroxyalkanoate (PHA)
- Fumaric Acid

The primary hydrocarbon-based feedstocks covered in the study are:

- Propylene
- Ethylene Oxide
- Propane

## 2.3 COST ECONOMICS COVERAGE

The cost of production locations covered in the economic analysis (as relevant) are:

- United Stated Gulf Coast (USGC)
- Western Europe
- Japan
- China

## 2.4 MARKET FORECASTS GEOGRAPHICAL COVERAGE

The study provides global coverage, with focus provided for the following markets:

- Global
- North America
- Western Europe
- Asia Pacific (excluding China)
- China
- Rest of World (ROW)

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The evaluations of conventional technology are based on Nexant's in-house information regarding process technology, augmented by contacts with licensors, engineering contractors and other experts in the industry. Analyses of emerging technologies are built up from reviews of patents, public domain information, and discussions with the technology development companies and engineering contractors.

Nexant uses proprietary and commercial state-of-the-art software tools to develop the technology and economic estimates. These are well established engineering tools in the process chemical industry and are used by major engineering contractors.

Commercial information and forecasts are developed from Nexant's extensive in-house databases, augmented with selected regional fieldwork.

Market projections are developed with the aid of Nexant's supply/demand computer modeling systems, such as Nexant's *ChemSystems* Simulator, which is discussed in more detail below.

#### Nexant's ChemSystems Simulator

Nexant's *ChemSystems* simulator is the proprietary simulation model developed by Nexant and used to generate all the analysis and forecasts of *ChemSystems* Online® and other offerings including the *ChemSystems* Petroleum and Petrochemical Economics (PPE) Program. The simulation model is an experience-based database running commodity petrochemical business logic algorithms to produce multi-scenario simulations of the global industry.

The integrated *ChemSystems* Online<sup>®</sup> Simulator simultaneously develops, as illustrated in Figure 4.1, forecasts of regional consumption, production, imports, exports and inventory changes for all commodity petrochemicals in all countries/regions.

The simulator is integrated from end-use markets back to petrochemical feedstocks. It considers inter-material competition, inter-regional price relationships, chain margins, product substitution, logistical costs and trade drivers. Costs and prices are integrated from crude oil, natural gas and petrochemical feedstocks to downstream products. One of the functional blocks, depicted in Figure 4.1, has been expanded on Figure 4.2 in order to illustrate the interconnectivity of these drivers and the complex relationships that are built into Simulator algorithms.



### Figure 4.1 *ChemSystems* Simulator Simplified Logic Diagram





Nexant's *ChemSystems* simulator delivers step change improvements in market forecasting and business/corporate planning, while reducing the resources and time required to evaluate multiple hypotheses and scenarios.

# Section 5

## 5.1 BACKGROUND

Nexant was established on January 1, 2000 and prior to that date, the staff of Nexant operated as a separate consulting group within a major engineering company. Nexant is now an independent company owned by a number of investors. Nexant acquired Chem Systems, Inc. on September 1, 2001, and the combined entity ("Nexant") now has access to even more enriched and extensive experience and resources, offering services that include:

- Master planning/feasibility studies
- Technology evaluation
- Techno-economic and commercial analyses
- Financial evaluation (cashflow modeling, etc.)
- Benchmarking
- Monitoring project implementation

Nexant is very well qualified to undertake technical, commercial, economic and financial evaluations from its own offices without the need to subcontract. Owing to its extensive experience, and known for its "out-of-the-box" thinking, Nexant's ChemSystems Group has also received the honorable award of "**Best Large Consultancy**" by the British Consultants and Construction Bureau. This award was contended by a number of companies. However, Nexant was judged the winner for its outstanding contribution in developing a real-time, on-line chemical industry simulator. Nexant's ChemSystems Group is now part of Nexant's Energy & Chemical Consulting (E&CC) division.

#### 5.2 DESCRIPTION OF SERVICES

Nexant is a specialist, not a generalist company. Areas of expertise for the E&CC Division (of which the ChemSystems Group is a part) are the energy and process industries, including oil refining, natural gas, petrochemicals, polymers, chemicals, pharmaceuticals and fertilizers. Our business has been built upon providing broad management consultancy services to leading companies active in these industries, as well as to banks, suppliers, governments and others interested in these sectors.

Nexant's strengths lie in its combination of technoeconomic, commercial and strategic capabilities. These "competencies" are described below, followed by an outline of the practice areas into which the E&CC Division is organized.

#### 5.2.1 Technology/Economics

From its foundation in chemical engineering and industrial chemistry, Nexant offers distinctive expertise in process technology and economic analysis. Assignments may be performed on a separate, stand-alone basis or as input to broader consulting engagements.

#### Services include:

- Economic and Financial Analyses of Projects or Businesses
- Valuation of Assets or Businesses
- Technical Audit of Existing Facilities
- Project Feasibility/Planning
- Technology Innovation and Assessment
- Comparative/Competitive Technology Audit and Appraisal
- Process Design and Cost Estimation
- Technology Availability, Screening, Licensing Arrangements
- Contractor Pre-Qualification, Evaluation and Selection
- Project Management Including Resident Advisory Services
- Price, Margin, and Profitability Forecasting

This discipline is supported by comprehensive economics, cost and price databases.

#### 5.2.2 Commercial

Based upon a technical and commercial understanding of the industries we serve, Nexant supports clients through a variety of market and commercial activities. As with our technoeconomic work, these commercial assignments may be performed on a stand-alone basis, but are more normally an input to broader consulting engagements.

Services include:

- Feedstock and Product Market Analysis
- Marketing And Market Research
- Supply/Demand Analysis and Forecasting
- Studies of Trends and Future Markets
- "Benchmarking" of Costs and Competitiveness
- Medium and Long Range Planning

The commercial discipline is supported by databases of global supply, demand, and capacity developments in all major petrochemicals.

#### 5.2.2.1 Strategic Planning

Industry specific expertise and an understanding of world market forces distinguish Nexant's work in Strategic Planning. Various innovative tools and methodologies tailored to the energy and process areas are used to challenge conventional thinking. Nexant extends its traditional

project team approach to engaging clients directly in the Strategic Planning process. Interactive client consultant relationships promote consensus, a critical factor for successfully developing pragmatic, implementable solutions.

Services include:

- Definition of Corporate and Business Visions
- Portfolio Planning
- Entry Strategy Evaluation
- Diversification, Acquisition, Divestment Studies
- Competitive Analysis and Business Positioning
- Global Competitiveness
- Trade Flow and Impact Studies
- Strategic Options, Selection and Implementation

# 5.3 ASSIGNMENTS UNDERTAKEN WHICH COVER ACRYLIC ACID, ITS DERIVATIVES, AND ITS FEEDSTOCKS

Nexant has completed a number of definitive studies covering acrylic acid, including both petrochemical and bio routes. These studies have analyzed the business structure and opportunities for acrylic acid within the context of a changing economic environment. In addition to studies specifically covering acrylic acid, Nexant has also been extremely active in engagements covering bio processes and routes in general. A sampling of our qualifications as related to acrylic acid and bio processes are as follows:

- **Competitive Intelligence**. Confidential Nexant provided a strategic assessment of how chemical and oil companies participate in commodity petrochemicals and an industry overview and outlook for the commodity petrochemicals in which the client currently participates including acrylic acid.
- **Petrochemical Industry Development Strategy**. Confidential Nexant was retained to assist the client in attracting further foreign investment in a target country. The primary focus of the study is to address what industries can be developed based on domestically available feedstocks, potential markets (locally, regionally and globally), and the competitiveness of such products to compete globally and locally. Acrylic acid chemical cluster was included in the study.
- China Market Analysis and Trend. Confidential Nexant was retained to provide a study of the markets in China for the derivatives under construction in order to select the correct product mix. The overall objective of the work was to provide market analysis and trends to assist in the selection of an optimal portfolio of products, including acrylates and crude and glacial acrylic acid.
- **Raw Material Trends** Nexant was retained to provide an independent consultant report covering the analysis of near-term raw material trends of the following products:

crude oil, steel, ethylene, ethylene oxide, acrylic acid, and naphthalene. The analysis includes simplified cost of production models, supply/demand analysis and quarterly price forecasting.

- Super Absorbent Polymer Cost Comparison Nexant was retained by an international chemical producer to provide a clear understanding of the cash cost competitiveness of their polymers project relative to five regional producers of super absorbent polymer. An evaluation of process technology and cost competitiveness for acrylic acid and acrylic esters was included in the study.
- New Technology Valuations: The Values of Technologies Under Development this multi-client study evaluated the intangible assets represented by chemical and energy process technologies that are in the research and development (R&D) phase. These technologies are not yet commercialized but appear to have significant economic value. The study surveyed twenty promising technologies and explains Nexant's assessment of their value. The technologies reviewed in detail included acrylic acid- direct oxidation of propane.
- Chemicals from Acetylene: Back to the Future? This multi-client study examined the viability of acetylene-based technology by reviewing and assessing both the technologies and costs for the various commercial acetylene processes, and the technologies and costs for the various historical and current acetylene derivative processes and theoretical processes that might be practical. Acetylene technology: partial oxidation process, calcium carbide process, acetylene recovery from steam crackers, and electric arc technology were covered in the study.
- Acrylates Market and Competitive Study This study focused on the Asian markets and provided an economics and competitive assessment on selected competitors supplying the Asian markets. It also provided a detailed focus on the China markets, particularly in Northeast China. The study covered ethyl acrylate, methyl acrylate, butyl acrylate and acrylic acid. Feedstock pricing, supply, price forecasting and cost comparisons were included.
- Acrylate Market Analysis The U.S. division of a major Japanese chemical producer came to Nexant for detailed information on the acrylic acid and ester supply/demand balance in North Central and South America. The information provided also contained profiles of existing producers with their captive consumption.
- Asian Acetyls, Acrylate and Esters For a chemical company developing an investment strategy for acetyls; acrylics and oxo-alcohols, Nexant prepared demand forecasts and identified demand drivers for the major Asian countries (Japan; South Korea; Taiwan; China; Indonesia; Malaysia; Thailand) in an effort to provide the client with an understanding of the basis for Asian demand growth. Products included acrylic acid; acetic acid; n-butanol; 2-ethylhaxanol; vinyl acetate; ethyl acetate; butyl acetate; butyl acrylate and 2 ethyl-hexyl acrylate.
- **Pre-Feasibility Study** Nexant was retained by a European chemical producer to prepare a pre-feasibility study for the potential opportunity to participate in a specialty

petrochemical complex in Saudi Arabia. The products covered in the study included acrylic acid and acrylate esters (butyl acrylate, ethyl acrylate and methyl acrylate). Nexant provided an economic and market analysis and forecasts, pricing, selection of process technology, and cost competitive positioning.

- Market Overview Nexant was retained to provide a market overview, price forecasts and a summary of environmental, health, safety, and handling and transportation issues for selected chemical products derived from the C<sub>3</sub> and C<sub>4</sub> streams potentially available from a refinery in Venezuela. Products covered in the study included butyl acrylate, ethyl acrylate and methyl acrylate.
- Acrylic Acid And Acrylate Monomer Study A Japanese client requested an analysis of the U.S. glacial acrylic acid and acrylate monomer supply and demand with a profile of the major purchasers. Products covered included acrylate esters, butyl acrylate, ethyl acrylate and methyl acrylate.
- Acrylates Market Study An Indonesian company, considering the construction of a new acrylates/oxo-alcohols facility, approached Nexant to evaluate the markets and pricing of these products in Indonesia and in the ASEAN region. The objective was to define market opportunities in Indonesia, export opportunities in other ASEAN countries and the pricing that the client can anticipate. The focus of Nexant's market analysis was demand by application, major markets in each area, regional capacities and pricing mechanisms.
- **Price Trends for Acrylates and Acrylic Acid** For a client seeking an independent view on the prospects and prices for purchasing substantial quantities of styrene butyl acrylate, ethyl acrylate and acrylic acid, Nexant reviewed historic prices for these chemicals in Europe and identified the major factors setting price and supply and provided price projections for the products.
- Market Analysis Nexant was retained by a Middle East polypropylene producer investigating options to add value to propane through dehydrogenation to propylene. Nexant provided relevant market, technology and profitability insights into the potential products based on propylene produced from a PDH plant. Acrylic acid, phenol, butyl acrylate and ethyl-hexyl acrylate were included in the study. Key findings and recommendations for optimum downstream derivative complex configurations were also included.
- Polyacrylate Polymers As Detergent Builders This report is part of Nexant's ChemSystems Process Evaluation/ Research Planning (PERP) Program which evaluates sodium polyacrylate as a detergent builder in the quest for a low phosphate detergent. The report provides the chemistry, process technology and production economics of polyacrylate polymers.
- Acrylic Acid This report is part of Nexant's ChemSystems Process Evaluation/Research Planning (PERP) Program that discusses the technology, economics and market analysis of acrylic acid and bio routes that use 3-HP, fumaric acid, and

glycerol. Cost of production estimates for crude acrylic acid, glacial acrylic acid, and several bio acrylic routes are included.

- Acrylic Acid This report is part of Nexant's ChemSystems Process Evaluation/Research Planning (PERP) Program that discusses the technology, economics and market analysis of acrylic acid, acrylates, acetylene and acetyls. Cost of production estimates for crude acrylic acid, methyl acrylate, ethyl acrylate, n-butyl acrylate, glacial acrylic acid, and 2-ethylhexyl acrylate are included.
- Petrochemical Market Dynamics: Propylene and Derivatives Part of Nexant's ChemSystems Petroleum and Petrochemical Economics (PPE) Program, this report analyzes the global market dynamics for propylene derivatives, including polypropylene, acrylonitrile, propylene oxide, acrylic acid, phenol and cumene.
- Super Absorbent Polymers (SAP) This report is part of Nexant's Process Evaluation/Research Planning (PERP) Program and discusses recent market, economic, environmental and technology issues for SAP. The report covers technical and economical assessments for shaft graft and conventional polyacrylate routes. Market outlooks are shown for North America, Western Europe, and Japan.
- Biotransformation Routes to Specialty Chemicals Includes consideration of conversions of natural oils, fatty acids, fatty acid esters, fatty alcohols and fatty amines, and fermentation technologies and commercial overviews of many bio-based product markets.
- Plants as Plants This report is part of Nexant's ChemSystems Process Evaluation/Research Planning (PERP) Program, and studied the emerging biotechnology, processing technologies and economics of producing and recovering polyhydroxyalkanoates (PHAs) - natural polyesters – by alternative routes of fermentation and in crops, including analyses of agricultural production economics, PHA extraction costs, byproduct biomass fuel utilization, and potential PHA markets.
- Biodiesel Glycerine Byproduct Market Dynamics For a major U.S.-based multinational agricultural and food company with a growing stake in biofuels, Nexant analyzed the market demand/price elasticity (with a growing glut of biodiesel glycerine byproduct), existing uses of glycerine, potential substitutions for others polyols such as propylene glycol and sorbitol, and potential future applications, including reaction derivatives of glycerine in various applications and fuel uses. Nexant considered the near term and emerging and long-term market outlets for USP and other refined grades of glycerine, as well as for crude biodiesel glycerine byproduct, which is of a more problematic quality than soap and oleochemical byproduct. The study required developing views of biodiesel growth, and pricing scenarios under various assumptions.
- **Biomass Ethanol Process Evaluation** Nexant performed a detailed technical and economic analysis of a commercial scale plant for the production of fuel grade ethanol from wood biomass via fermentation, a process developed by a national energy laboratory. Among the goals of the program was the incorporation of the latest R&D

developments into the design. The results from this study were compared against earlier designs.

- Biomass Ethanol Development Technical Support Under a multiyear program, Nexant provided technical support for the SERI program to develop viable alcohol fuels production technology based on cellulosic feedstocks. Activities included: investigation of prototype cellulose to ethanol via hydrolysis plant designs for capacities of 50 MM to 250 MM gallons per year; detailed design and capital cost estimate for an anhydrous ethanol plant based on enzymatic hydrolysis of hardwood chips; techno-economic evaluation of proposed processes including biomethanation of biomass pyrolysis gases and liquid fuels from cellulosic biomass.
- Chemicals from Corn This was a broad-based study for the National Corn Growers Association (NCGA), funded by the U.S. DOE, to identify and screen chemicals that could be feasibly produced from corn. The study considered a wide range of potential sugars, and fermentation-derived acids, alcohols, and other building blocks, but emphasized fuel ethanol derivatives, including basic petrochemicals, solvents, intermediates and specialties, and application of the Reactive Distillation technology sponsored by the NCGA. The basic economics of ethanol production and potential improvements, economies of scale, logistics, and other production and value chain issues, are addressed in the study.
- Enzyme Process Assessment Nexant assessed the impact on process economics and energy consumption resulting from substituting immobilized cells of *Zymomonas Mobilis* for conventional yeast in a commercial corn-based ethanol facility.
- Ethanol Market and Cost Competitiveness Evaluation Nexant was retained by an ethanol producer and its financial advisor to provide an independent market study and evaluation of project cost competitiveness to help raise funds to convert an existing sugar- and corn-based ethanol plant in Louisiana to process organic waste (biomass) as a feedstock.
- Synthesis Gas (Future Sources) This report reviewed the technology for production of synthesis gas (H<sub>2</sub>, CO mixtures) from a number of sources. Most emphasis was devoted to coal and biomass (municipal solid waste and wood) gasification and new gasification technology. The report discussed downstream processing requirements and examined coal and biomass properties and their impact upon gasifier design. The economics of producing industrial fuel gas (gasifier effluent after acid gas removal) via different routes were compared to the direct use of natural gas and low sulfur fuel oil.
- **Technology, Company, Finance, and Project Due Diligence in Biofuels** Nexant has performed a number of recent due diligence assignments for financial institutions assessing the feasibility and value of technologies, companies, businesses, or proposed projects focused on bioethanol or biodiesel.

# Section 6

# Contact Details and Subscription Information

## 6.1 CONTACT DETAILS

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