Prospectus

New Technology Valuations

The Values of Technologies Under Development

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1.1 OVERVIEW

Nexant has completed a multi-client study which analyzes the values of new technologies in the chemical and energy processing industries. These are chemical process technologies that are not yet commercialized, but which may represent attractive opportunities for investments in R&D and commercial development by technology and operating companies seeking to enhance their value creation for the benefit of their shareholders and other stakeholders.

1.1.1 Overall Value Premise

Developing and investing in advanced technologies are among the relatively few ways in which companies can create truly exceptional value. The history of the chemical and energy industries is full of examples of technologies that produced enormous value, both for the developers as well as industry and society as a whole. However, in order to maximize the potential net value creation from technologies, it is critically necessary to make insightful judgments about the opportunities involved. These judgments then allow costs to be compared to potential rewards from the technologies, and for companies to pursue the most attractive opportunities their technology strategies.

This study provides subscribers with the following important information and analysis:

- A survey of significant new technologies under development in the chemical and energy industries
- A screening of these technologies, resulting in 24 being selected for study and valuation in this report
- A valuation analysis of the 24 selected technologies using a net present value approach assuming a licensing business model applied on a consistent basis
- An explanation of the valuation methodology and approach employed in the study that will allow subscribers to make their own directional inferences on potential alternative valuations based on different scenarios for the technologies or industry trends, and compare these to their proprietary opportunities

In summary, this study will help subscribers analyze the potential financial rewards for new chemical process technology developments and investments.

1.1.2 Nexant's Experience

Nexant has a 40 plus year history as an industry-expert consulting firm, based on the long heritage in our original founding organizations, Chem Systems and Bechtel. Our work in analyzing technologies, both technically and economically, has continued throughout that time. Since we are also independent and unbiased (Nexant does not invest in or take positions in technologies or companies, either as a developer or an operator), we are in an excellent position to make realistic and fair judgments about the future prospects of these promising new technologies.

1.1.3 Approach for this Study

In this study, we analyzed new technologies (which are not yet commercialized) by employing a consistent approach and using non-confidential information. This was a disciplined analysis, but appropriately flexible to take into account new findings as we performed the study.

Our work to develop this study employed the following steps to develop the value estimates.

- Review the technologies and screen them to select 24 technologies for detailed study
- Use patent information, for cases in which patents have been published
- Otherwise, use anecdotal information in the public domain
- Develop our estimates of the capital investment and operating characteristics (stoichiometry and operating costs) for the new technologies on the assumption that they are implemented
- Develop an estimate of the market opportunity for each technology
- Apply a consistent valuation approach, using normal discounted cash flow (DCF) methods to estimate the value of technology/intellectual capital (intangible assets)
- The multi-client study report documents our analysis and conclusions

This analysis and the conclusions from it are a valuable source of reference and comparison for all companies involved in the chemical and energy processing industries. In addition, it serves as a benchmark against subscribers' own unique and in most cases proprietary opportunities for technology development or investment, which may be related in various ways to the "public domain" information about technologies that are addressed in the study.

This prospectus describes the background of why this 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

The chemical industry can be viewed as now having been in existence for over three centuries. During that time, many especially significant technological advances were made starting in the mid-19th century, while the energy processing industries developed more or less simultaneously, starting with the washing of coal and the early petroleum refining technologies.

Chemical processing advancements have dramatically changed and contributed to the world's economy. Chemical technologies are involved in every step in the creation of products and value in the global economy, from the initial steps of processing raw materials obtained from mining and petroleum, agriculture, and other supply sources, to progressively advanced materials, substances, fuels and chemical compounds that are either end products or are used in other industries' products and services.

By the late 1990s, the chemical industry in the United States had grown to produce approximately $389 billion worth of products annually and employed over 1 million workers, exporting over $71 billion worth of chemicals. Global growth has also been impressive. For example, in 2004, the global top 50 chemical producers accumulated sales of approximately 587 billion dollars with a profit margin of 8.1 percent and research and development spending of 2.1 percent both against sales. The global economic slowdown that began in 2008 is expected to interrupt temporarily growth in chemicals, and perhaps energy demand. However, with a growing worldwide population and since chemicals are essential in all aspects of modern life, 2009 will most likely come to represent a relatively modest lull in this growth pattern.

1.2.1 Importance of New Technologies

Due to the economic importance of the chemical and energy industries and opportunities in the complex modern global economy, companies are always in search for new technologies to achieve success for their enterprises. This is because successful technologies go through life cycles. While the timing of the cycles are highly variable, the result is that over time the profitability of any technology will decline significantly as it becomes commoditized.

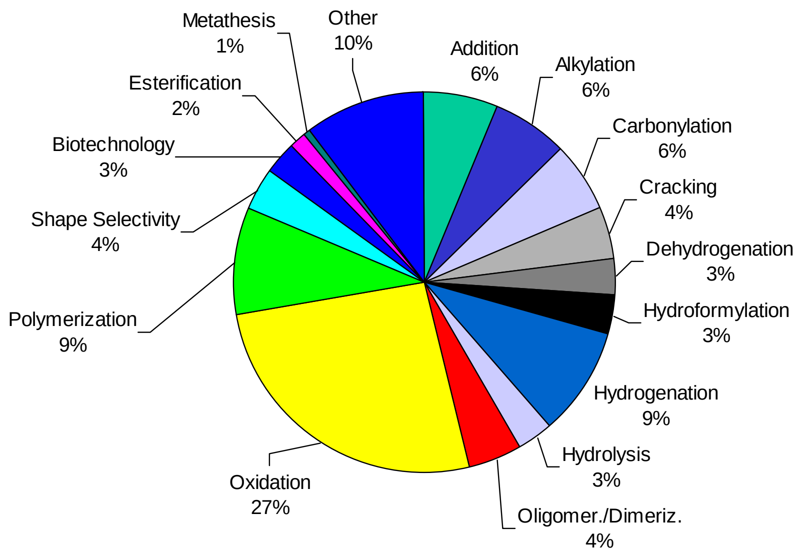
Due to the many different types advancements and continuing research in the chemical and related industries, it is challenging to sort the upcoming new technologies into categories. Additionally, to attempt to organize such a list by product would also prove to be difficult due to the myriad number of products that are available in the chemical industry.

One way to reasonably categorize new technologies is based on a common commodity chemical. Products with a common commodity chemical could be grouped together. Under each commodity chemical, one could list the technologies that have that commodity chemical either as its feedstock of its product. Instead of having several categories with only a few entries, when sorting by commodity there are larger but fewer categories, facilitating the sorting/searching process. We used this approach primarily in this study to categorize the technologies.

We should caution that in our view, the complexity of the chemical and related process industries, such as petroleum and paper, makes it difficult to describe the chemical industry in any direct way that is completely satisfying. For instance, we indicate below for reference two other common ways to provide an overall description of the chemical industry: (1) by the numbers of technologies that use different basic chemistries, and (2) by the total output quantities that are produced from the different basic chemistries.

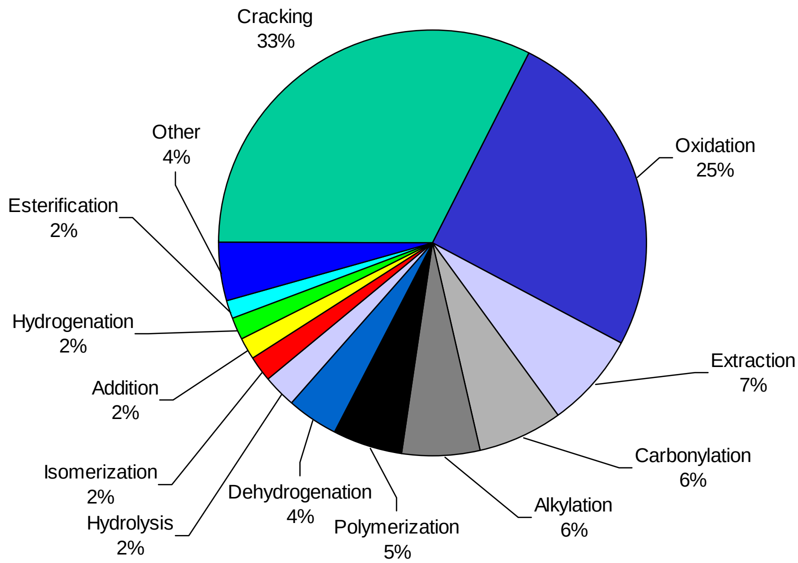
The types of technologies used in the chemical industry in the period of 2004 to 2006, ranked by the estimated total number of each type of chemistry, are indicated Figure 1.1.

Figure 1.1 Chemical Industry Technologies
(By percentage of total applications)



The characterization of the chemical industry by the total production (in weight) produced via the types of chemical reactions, results in a much different breakdown (Figure 1.2).

Figure 1.2 Chemical Industry Technologies
(By percentage of total chemical production output)



Please note for the sake of clarity that the above figures do not include petroleum refining or natural gas treating, although those sectors and coal upgrading also utilize many chemical processes.

1.2.2 Achieving Value from Technology

Technology developers can achieve value from their new technology developments in many ways. Among the most commonly used business models are the following:

- Build-Own-Operate: In this model, the technology developer commercializes the technology itself, to build and operate the plants for its own account, thus being an operating company supplying products to the market.
  - An example is the well-known development of the epoxidation technology to produce propylene oxide in the 1960s and 1970s by Halcon, Oxirane, and ARCO Chemical.
  - There are variations on this approach. For instance, the commercialization may be done via a joint venture in which the technology developer teams with a regional or industry experienced partner.

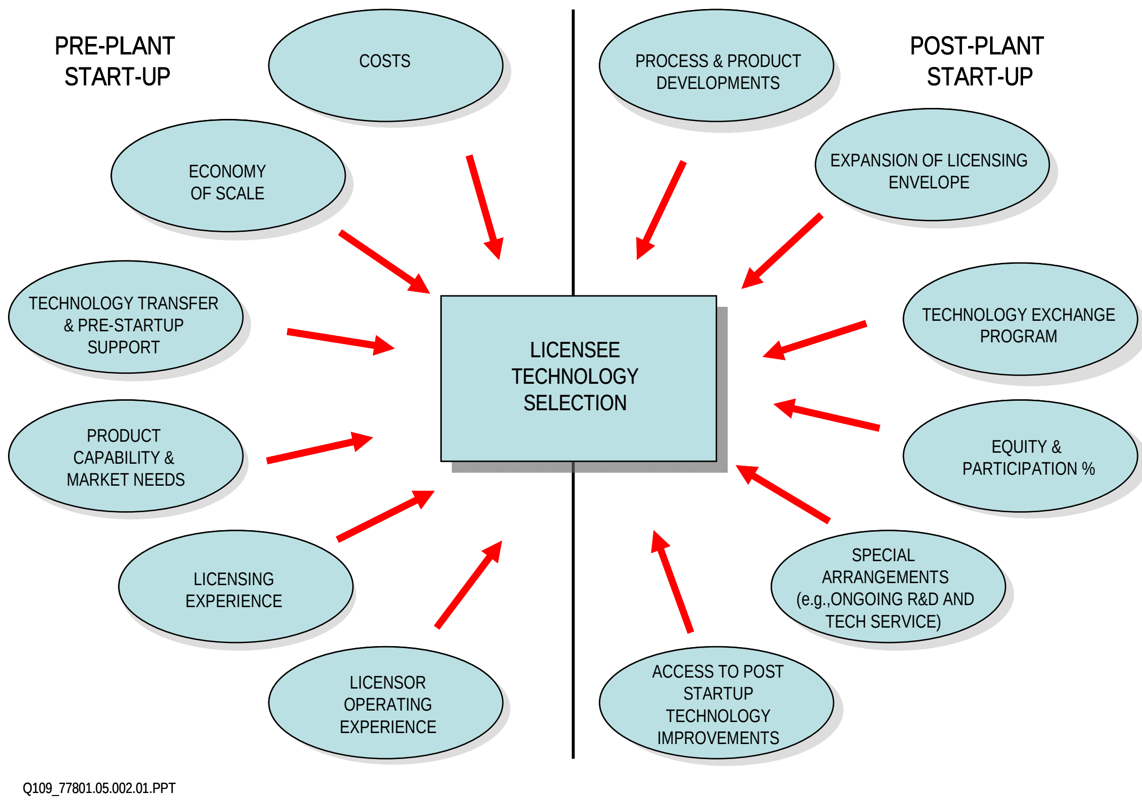
- Licensing: This route is frequently the norm for technology companies that do not find it optimum to transform into a mixed technology and manufacturing company model.
  - Licensing the technology to operating companies, for example, was the route to value taken by Union Carbide in the 1970s with the breakthrough Unipol technology for linear low density polyethylene. (Although UCC also utilized Unipol technology in its own plants).
  - It is also the approach to the market employed by UOP in the petrochemical and petroleum refining industry sectors.

- Licensing with EPC: Combining Licensing with EPC (engineering, procurement, and construction) activities to design and build plants for operating companies is a common approach. This approach to achieve value for technologies is that employed by a number of engineering oriented companies worldwide.

Oftentimes, the business model may change over the life of the technology. For example, Chevron developed many hydrotreating-related technologies starting in the 1950s and 1960s. After proving them in its own refineries, Chevron then also actively licensed the technologies. Later on in the life of these technologies, Chevron formed a joint venture with Lummus Global (a leading engineering company) to conduct the licensing activities for these technologies.

The mechanics of technology selection by licensees are, of course, complex in that they take into account the full range of technical and commercial factors that influence the success of a commercial investment in plant and equipment and operation of a manufacturing business. These are illustrated in Figure 1.3 for typical technology licensing situations.

Figure 1.3
Technology Selection Factors – Typical



When a company develops and implements its own proprietary in-house technology to make products for the market, the business, and value-related factors would be related to these, but would be at least somewhat different.

Nexant believes that the decision to either license a technology or to use it in-house is subject to complex factors and a somewhat subjective analysis. It will critically depend on numerous factors, including the financial and organizational strengths of the technology sponsor, but most important of all may be the value-added missions of project sponsors. These are too varied to be considered in this study.

Thus, in this study Nexant estimated the values of the technologies based on the Licensing business model. We have chosen this approach because we believe it to be the most relevant for comparisons of different technologies on a global basis. In our judgment, the Build-Own-Operate and the Licensing with EPC business models definitely are relevant for various types of technology holders, but would produce valuation results that would likely vary more significantly between companies and technologies.

2.1 OVERVIEW

Nexant first screened and then analyzed the new technologies (not yet fully commercialized) by employing a consistent approach and using non-confidential and therefore unrestricted information. Thus, although process-specific information (patents, other public information releases from technology developers, and analogies to other proven technologies) was utilized in the analysis, there were no restrictions on the ability of subscribers to this study to use the results or information from the study for their own analysis and decision-making.

2.2 SCOPE OF WORK

In preparing the study, we performed the following steps for each technology analyzed:

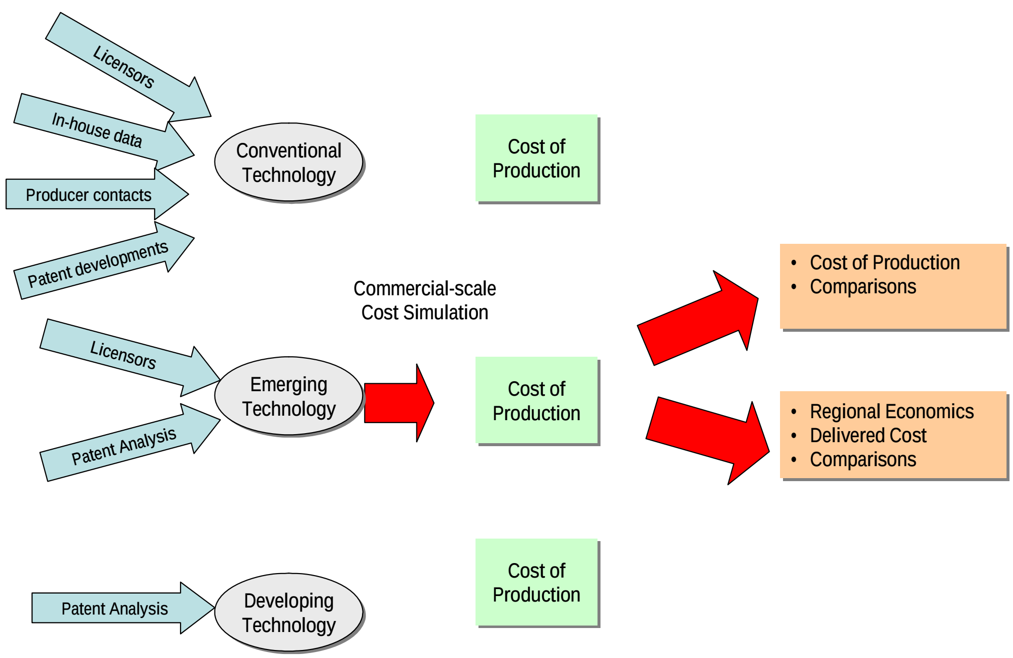
- Performed a screening review of all the prospective technologies in our Initial List, in order to conclude which ones had adequate information in the public domain for us to do a reasonable analysis of a “most likely” valuation case.
- Selected 20 of the technologies for further study and inclusion in the rest of the work. Some early subscribers nominated new technologies, for which there was a reasonable amount of public domain information, to be included in those studied. We included those in our list of 24 technologies to be valued.
- Used patent information, for cases in which that is published regarding a prospective development.
- Otherwise, used anecdotal information in the public domain.
- Developed our estimate (hypothetical) of the capital investment and operating characteristics (stoichiometry and operating costs) for the new technologies.
- Developed an estimate of the market opportunity for each technology and an estimate of the product price that may be achieved for the product.
- Developed an estimate of a likely return on investment percentage (ROI %) that could be achieved by employing each technology.
- Estimated the addressable market for the technology and the likely market share that it would achieve.
- Applied a consistent valuation approach, with normal valuation parameters (such as life of the technologies, discount rates, costs to service the licensing business) to estimate the value of technology intellectual capital (intangible assets).
- Provided a report documenting our analysis, valuation premises and assumptions, and conclusions.

2.3 ECONOMICS

For each chemical and energy process chosen as a result of the screening step for valuation, Nexant estimated a simplified "Cost of Production" profile. In addition, a market profile was used to identify the market potential for the product, and a pricing estimate for raw materials and products.

The Cost of Production profile was developed using the approach shown below in Figure 2.1. It was necessarily approximate, due to the lack of definitive information in the public domain, and also due to uncertain nature of technologies that are in a pre-commercial status.

Figure 2.1 Nexant's Typical Approach to Developing a Cost of Production Profile



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In all cases, the Cost of Production profile, market profile and price estimate were appropriate to the opportunity represented by the technology. It is intended to be generally global in applicability, but if the opportunity was fairly evident as primarily a regional opportunity, then the profile, etc., was developed as an estimate for a particular region.

The Cost of Production profile format was similar to or an approximation of that shown in Table 2.1 (an illustrative example in this case, for a simple and proven-technology example for propylene recovery).

Table 2.1 Example of a Cost of Production Estimate for: Propylene Process: Recovery from Refinery Propylene, USGC Location

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

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

The cost of production ("COP") estimate for each technology was used in estimating the attractiveness of the economic opportunity for the technology, and provided guidance in estimating the licensing fee for each technology. In addition, the competitiveness of the cost of production of the technology was important in Nexant reaching a judgment on the addressable market as well as the likely penetration (market share percentage). Thus, the cost of production estimate was an important factor in the technology valuations.

Depending on the market circumstances appropriate to each technology, we chose to do the COP modeling for each technology for either a recent historical year, or a projected future year, depending on which we felt was more relevant to making the decisions on addressable market and market share.

2.4 VALUATION APPROACH - GENERAL

The valuation approach used in this study was that of a typical technology (i.e. intangible asset) valuation, based on a discounted cash flow (DCF) approach analysis of the prospective net licensing fees expected for each technology.

2.3.1 Intangible Assets: Definition/Categorization

2.3.1.1 General Background

This section is intended to provide a general background for the subject of intangible assets, sometimes termed Intangible Capital. Intangible assets can be categorized into four classes: human, organizational, marketing, (or relational), and production. Human capital accounts for the investments made by companies in the skills and knowledge of its workface. Organizational capital accounts for the organizational architecture and the systems for monitoring activity within the company. Marketing/Relational capital represents the control and strategies for distribution networks and markets. Production capital, the type that is of interest in this review, includes the development of new products and manufacturing processes.

The sale value of intangible assets is generally most strongly influenced by three attributes: production uncertainty, fragmented accountability, and non-separability. While tangible products can be mass-produced, the production of an intangible is more of a heterogeneous dynamic (bi-matrix desired business process). Additionally, the difficulty in properly accounting for returns from investments in intangible assets is much higher. However, with cases that deal with technology (and other situations that rely on tacit knowledge), oftentimes the cost of imitation can equal the costs of invention thus making the value added to the creator very high. Intangible assets are also frequently incapable of being separated from the originating business unit without a loss in value.

2.3.2 How to Value Intangible Assets

Assigning value to intangible assets can be problematic. Nevertheless, it is a necessary management task when investing in new technologies.

The valuation process involves multiple steps and different approaches. There are three approaches to estimate asset values in general: the Cost, Market, and Income approaches. The

Cost Approach values technology based on the cost used to create it. It is not that informative when it comes to assessing technology or intellectual assets. The second approach, the Market Approach, takes into account recent transactions involving the transfer of ownership of technologies similar to that in question. This approach also usually serves little use in evaluating intangible assets due to both (1) the lack of availability of a ready market for matters such as intellectual property rights, and (2) the circumstance that intangible assets such as technology rights, are extremely diverse and cannot usually be compared very well to each other on a basis of similarities. Intellectual property is generally not developed to be sold, but when it is, it is often part of a larger transaction where the details are confidential and not available to the public. The last approach, the Income Approach, values intellectual assets by looking at the present worth of economic benefits of the asset and examining the future income-producing capability of the asset. This is considered the most typically insightful approach for valuing technologies, especially technologies under development. Nevertheless, applying the Income Approach in a thoughtful manner to new technologies is by no means a trivial exercise, since it requires, in effect, estimating a business case or business plan for each technology.

It is noted that by necessity the valuations performed during this study were of a preliminary nature in the sense that they were developed without using any confidential technical or market data. (Before a technology can be valued definitively, some form of confidential-level due diligence on that technology must be done. That process includes a commercial analysis, the current developmental status of the technology and a financial analysis. Some consideration may also need to be given to the track record of the inventor/development entity.)

2.3.3 Value Proposition

This study provides useful insights into how successful the developing technology will likely be in the real world. The relation of the estimated valuations from this study, combined with our transparent explanation of the valuation bases and premises, provides a valuable impartial guide for companies involved in investing in, developing, or licensing new technologies.

Thus, the following steps were performed in order to develop this study's conclusions on each technology:

- Define the product and the technology
- Assess its expected or most likely industrial/commercial value
- Identify the typical end user(s) of the product or intermediate product
- Estimate the size of the market for the particular product (addressable market)
- Identify the competitive edge or uniqueness of the technology in comparison to the already existing products/technologies in the market
- Evaluate the market's maturity
- Identify existing regulatory or liability considerations in commercialization
- Assess prospective licensees (by number of reasonably likely licensees)
- Judgment on the length of the product cycle

After these steps are performed, the technology can then be valued.

When estimating the licensing royalty fee rate for the technologies, factors such as perceived commercial risk and nature, and stage of the development of the technology, along with technical, environmental and strategic issues, are considered along with the investments and returns associated with the technology. This is based on the assumption or premise that the attributes of the intangible asset can be at least generally compared to complementary or similar technologies known in the industry. In addition, while royalty rates for licensing technologies vary substantially from one technology to another, generalizations were made when it comes to the patterns of how the value of a technology is affected by certain factors.

Performing a "present time" valuation of intellectual assets from future cash flows of that asset requires one to appropriately discount the anticipated revenues. The discount is applied to reflect the risk in the predicted cash flows from the perspective of the current date. There are a number of issues involved when determining the discount rate, and these include interest rate risks and market risks, as well as the asset's technical and other commercialization attributes. In this study, the discount rate was determined per normal financial criteria for performing business and asset valuations, consisting of a weighted average of the cost of debt and the cost of equity and a reasonable component for the return to compensate for the risk in achieving it.

As the risk involved in a technology decreases, or the reward from the technology's success increases, the usefulness and potential for competitive advantage increases and thus the value in licensing the technology would increase (assuming other factors were to remain unchanged). In the commercial arena of technology values, as the economic impact becomes more certain, commercial risk decreases, and the useful economic life is likely to be extended, thus leading to an increase in the value of the technology.

2.3.4 Transparency of Valuation Estimates

In explaining our valuations in the report, we describe the key aspects of our work and the approach we employed, especially as to key valuation aspects assumptions for each technology valued:

- The purpose of the valuation: To estimate the values of technologies assuming that they are owned by an independent technology licensor.
- The characterization/description of the asset: The nature of the technology and what the inputs (raw materials and other key inputs) and outputs (products and by-products) of the process are expected to be. In general, we kept our characterization at a generic level (not any particular company's technology. But, if we believed we knew, based on public information, that one or more companies were developing a generally similar technology to the one studied, we commented on those as appropriate.
- The premise or basis of the valuation: How the asset (new technology) will achieve revenues and profits, assuming the most advantageous ("best") use of the technology that is reasonable, such as the market size for its product, the number of licenses likely to be

sold per year, the market penetration of the technology, and our judgment of a licensing fee per license to be sold.

- The methodology of using the technology: These include estimated costs and revenues, and the estimated business profile of the technology.

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4.1 OVERALL APPROACH

The evaluations of prospective technology developments were based on Nexant's in-house non-confidential information as published or available publicly regarding process technologies. These were augmented selectively by reviews of public patent and selective contacts with other experts in the industry done on a non-confidential basis. Nexant used typical and commercial software tools to develop the technology profiles, market profiles, COP estimates, and economic estimates. The economic evaluations were premised as typical USGC based, and with estimated capital costs that are appropriate for "factored estimates". These do not reflect specific site issues, but rather the USGC region as a whole.

The study was completed in December 2009.

4.1.1 DCF Analysis

The DCF analysis was a typical calculation based on estimating license fees as revenues and applying reasonable estimates of costs to sell and service the licensing of the process technologies. Thus, it conceptually applies for valuation purposes at the time just after the new technology has been advanced to the point of being accepted by the chemical/energy industry as a reasonable technology to utilize in a commercial scale production facility.

Before performing the licensing DCF analysis, we first developed a conceptual Cost of Production Profile that tested the basis of the premise that the technology will be licensable.

4.2 INITIAL LIST OF TECHNOLOGIES TO BE REVIEWED

We have grouped the Initial List of potential technologies into eight (8) categories, as follows: Methane, Ethylene, Propylene, Butadiene, Benzene and Toluene, Biotech, Other Chemicals and Fuels. We selected at least one technology from each of the categories. The Initial List is shown below. In the Initial List we included some brief comments on our current understanding on the status of the public information on these prospective technologies. We further developed our understanding of the current status of each of these prospective technologies as we proceeded with this study.

We anticipated adding some additional new technologies and perhaps categories to those in the Initial List when we began work on this study.

4.2.1 Methane

4.2.1.1 Methanol - Methanol Synthesis Directly from Methane

A direct methane to methanol process, which would avoid the need to first produce synthesis gas, would make methane a much more attractive and valuable energy source. Methanol, being a liquid, is a much easier product to transport. While it is thermodynamically possible for methane to be converted directly into methanol, the production of carbon dioxide is favored in the process.

To remedy this, it is necessary to try to control the oxidation of methane so that it stops after the production of methanol before CO_2 is produced when methane is deeply oxidized. However, it is not easy to control the oxidation and there has been much research with partial oxidation as the goal.

The already existing methods for creating methanol directly from methane are considered either expensive or untried, preventing them from commercial development.

4.2.1.2 Dimethyl ether - Methanol Dehydration

The process of separating unconverted methanol from DME for recycle processing into DME has not been accomplished in a large-scale conversion. Theoretically, it is desirable to develop a process for the production and separate recovery of DME in isolation from unconverted methanol and co-product water in the production of DME. If this process could be fully developed, it would enable the large-scale production of DME as a practical commodity chemical thus making it economically viable.

DME is currently produced via the dehydration of methanol but its manufacturing cost is relatively high and its use as a fuel is not considered to be generally practical except in selected locations.

4.2.1.3 Dimethyl ether - Direct from Syngas

Although a gas phase single step syngas to DME process would provide the same synergy for greater production rate as in LPDME, the process is most likely to be still subject to the limitation in heat removal, therefore preventing effective realization of the synergy.

This process could potentially be commercialized if there are further improvements in the technology.

4.2.1.4 Dimethyl ether - OCM (Oxidative Coupling of Methane)

Despite its attractiveness, OCM reactions have not been used commercially as a method for ethylene production from natural gas. The main reasons for this include the following: the performance of catalysts is limited thermodynamically, the reactions in OCM and side reactions are highly exothermic making it difficult to scale up the OCM process, and also hindering the scale up process is the undesired pre-catalytic and post catalytic reactions having an adverse affect on the OCM performance.

4.2.1.5 Methanol to Olefins

This technology is nearing the status of demonstrated and economical, but has not been completely proven as commercially viable, although there are a couple of installations operations. If this technology is completely commercialized, it would be an important part of producing olefins from coal (via gasification) or methane (for instance, from remote stranded gas).

4.2.1.6 Methanol to Aromatics

Methanol produced from remote natural gas reserves could be a source for numerous chemicals. Chevron Phillips has patented a novel catalyst combination that converts methanol to aromatics, especially xylenes. The technology appears to be a combination of MTO (UOP's process uses a catalyst similar to the one described in the patent) and MTG-Methanol to Gasoline (Mobil's process that also contains methanol to aromatics).

4.2.1.7 Methane to Benzene

Mitsui Chemicals and Mitsubishi Chemical have both announced plans, but details of their technologies are not available. Mitsui plans to open an R&D center in Singapore to develop a catalyst to produce benzene from natural gas. R&D is expected to take about 5 years, with the goal of producing at least 600 KTA of benzene. Mitsubishi has claimed to have an industrial process to produce benzene and hydrogen from coke oven gas and carbon dioxide. They have been planning to start construction of such a 150-250 KTA benzene plant. In addition, Conoco Phillips was awarded a patent for a catalyst and a process to produce aromatics from methane. That process is not specific to benzene, as it also produces toluene, xylene, and naphthalene.

4.2.1.8 Methanol from CO_2

Mitsui has announced that it is building a pilot plant in Osaka in order to use captured carbon dioxide from industrial processes to produce methanol via a proprietary new technology. This or other similar technologies, if any are being developed, could be attractive in reducing greenhouse gas emissions from industrial facilities and hopefully serve as a source of incremental hydrogen production.

4.2.2 Ethylene

4.2.2.1 Ethylene - Catalytic Ethane Cracking

Currently, the catalyzed dehydrogenation of propane to propylene has been commercialized but there has not been an economically attractive commercial process developed for ethane dehydrogenation. In comparison, ethane dehydrogenation involves even higher temperatures than for propane and while it is possible for dehydrogenation to occur, there is difficultly in the selectivity of the process. The loss in selectivity stems from side reactions including cracking and coking that are brought on with higher temperatures. Additionally, any significant yields from ethane dehydrogenation can only be obtained at very high temperatures where it is difficult for catalysts to survive.

The side reactions lead to the formation of coke and heavy material, further impairing the efficiency of any catalysts. Because of this, a regeneration process is necessary. All these factors lead to a process that is not yet economically feasible for commercial use.

4.2.2.2 Ethylene - Catalytic Naphtha Cracking

One factor that impedes the entrance of catalytic naphtha cracking into the commercial world is the fact that higher-severity naphtha cracking leads to less favorable economics. Because a naphtha cracker is more complex, it has three times the products to sell and involves much more working capital. Another problem with catalytic naphtha cracking is that selectivity to ethylene declines as naphthalene content increases.

4.2.2.3 Ethylene – via Semi Permeable membrane

Researchers at Argonne National Laboratory (U.S. DOE) have developed a hydrogen transport membrane ("HTM") which can be used to produce ethylene from ethane, without having to use pyrolysis as in the conventional steam cracking approach. This HTM technology appears promising for potential commercialization.

4.2.2.4 Ethylene - Catalytic Ethane Partial Oxidation

An alternative to steam cracking is to catalytically crack paraffinic hydrocarbons in the presence of oxygen to form mono-olefins. Under autothermal conditions, the feed is partially combusted and the endothermic cracking process is driven by the heat produced from the combustion. Due to the heat produced, an external heat source is not needed. The downside to the process is that substantial amounts of carbon oxides are usually formed and the selectivity to olefins is generally low compared to that of thermal cracking.

4.2.2.5 Ethylene Glycol - Direct Ethylene Oxidation

There have been several instances cited in literature where companies have developed glycol processes based on direct catalytic oxidation of the olefins. The olefins are oxidized into glycol acetates and these acetates are then hydrolyzed into glycols. There have been rough design and economic studies performed on a direct oxidation process for large-scale production of ethylene glycol and the economics compared with the two-step synthesis through ethylene oxide. The process of direct oxidation continues to appear quite promising, given savings in both investment and production cost.

4.2.2.6 Cyclic Olefins/Polymers - Solution Process

The production of cyclic olefins/polymers is still a relatively new process and technology is still in the research phase. Before the use of metallocene based catalysts, polymerization and copolymerization of cyclic/bicyclic olefins with Ziegler catalysts resulted in polymers with 30 percent of their structures resulting from ring opening metathesis type reactions.

With the discovery of metallocene catalysts, it is now possible to homo- and copolymerize cyclic/bicyclic olefins to high molecular weight linear polymers without any ring opening metathesis reactions.

4.2.2.7 Vinyl Chloride Monomer - EVC Ethane Based Process

Ethane based production of vinyl chloride has been a targeted goal in VCM process research for a while and has proven to be a difficult one. There have been a number of attempts to develop the ethane-based process but none of the processes have been fully commercialized.

If successful, EVC's (INEOS' European Vinyls Corp.) ethane oxychlorination process could be quite competitive due to its low raw materials cost outweighing somewhat higher investment.

However, there may be an increased investment cost due to any further process requirements that are not already known.

4.2.2.8 Octene-1 – Ethylene Tetramerization

Full-range technologies produce a range of alpha olefins that must be separated and purified to obtain the desired alpha olefin(s). Cost-effective, on-purpose technologies for certain alpha olefins are desirable to target those that have the highest growth and margins. This would also simplify plant design and minimize the need to service the additional markets resulting from full-range alpha olefin production. Sasol has developed a catalyst system and operating conditions that provides a fairly selective reaction to octene-1. An example in a patent gives the following product: 66.3 percent C_8's (99.4 percent octene-1) and 21.7 percent C_6's (82.9 percent hexene-1). Investment costs are estimated to be fairly low relative to conventional alpha olefins processes, but operating costs are significantly higher with market priced ethylene. Application in low-cost ethylene regions would increase competitiveness significantly.

4.2.3 Propylene-Related

4.2.3.1 Propylene - Ethylene/Butylene Metathesis

This technology is now offered by Lummus (CB&I) and has been demonstrated. In this process, two reactions take place; Propylene is formed by the metathesis of ethylene and butylene-2, and butylene-1 is isomerized to butylene-2. Lummus claims that the process can handle a variety of mixed C_4 streams and compositions. Axens is also offering its version of this technology.

4.2.3.2 Acrylonitrile - Propane Ammoxidation

This new route has received much attention (Asahi Kasei, INEOS), and appear to be moving full commercialization. Propane costs are estimated to be substantially lower than in previous studies of propane technology, but the propane savings were offset by higher costs for the ammonia and H_2SO_4 needed for ammonia neutralization.

Propane technology to produce acrylonitrile directly, could prove to be useful if the difference in propane and propylene price is substantially large or when propylene supplies are restricted.

4.2.3.3 Oxo Alcohols - Unmodified Rhodium Process

In the most widely applied oxo alcohol production process, normal and iso-butyraldehydes are produced by reacting propylene with synthesis gas in the presence of a homogeneous modified rhodium catalyst. This process proves to be superior to the method involving the unmodified rhodium process. The unmodified rhodium process apparently uses octenes and may be considered commercialized.

4.2.3.4 1,3-Propanediol (PDO)- Acrolein Process

The reason that this process has not been more widely commercialized appears to be the relatively low yield achieved to data in commercialized acrolein/glycerine routes. In addition to its use in PTT polyols, PDO has applications for use in runway de-icers. Research is thought to be underway to further develop this route. In a related development, the DuPont Tate & Lyle joint venture is producing PDO from corn sugar in Loudon, TN.

4.2.3.5 Polytrimethylene Terephthalate (PTT) - Esterification/Polycondensation

There are a few reasons why the production of PTT has only appeared on the market more recently instead of when it was invented about 60 years ago. One of the reasons is that when it was invented, polyethylene terephthalate (PET) was proven to be the product with a broader application potential in different industrial fields. Additionally, there was a limited availability of PDO, which is crucial in the industrial production of PTT. Along with being limited in availability, PDO was also expensive, further deterring the production or research in production of PTT.

There are two main factors that will drive further industrialization of PTT – more efficient polymer production/processing technology and the price of PDO.

4.2.4 Butadiene

4.2.4.1 Styrene - Styrene via Butadiene Dimerization

This can be done by a combination of cyclo-dimerization followed by dehydrogenation. In situations where there is surplus butadiene, this may be attractive.

4.2.4.2 Octene-1 from Butadiene

Full-range technologies produce a range of alpha olefins that must be separated and purified to obtain the desired alpha olefin(s). Cost-effective, on-purpose technologies for certain alpha olefins are desirable to target those that have the highest growth and margins. This would also simplify plant design and minimize the need to service the additional markets resulting from full-range production.

Dow has a patent covering the telomerization of butadiene with methanol, hydrogenation of the intermediate, followed by cracking to form octene-1 and methanol. Nearly 96 percent of the contained butadiene is converted and selectivity to the desired intermediate is 89.4 percent. However, selectivity to octenes in the cracking step is only about 66 percent, of which, 95.7 percent is octene-1. Preliminary economics indicate fairly high investment capital and high operating costs due to the high cost of mixed C_4's. Application in areas with no alternative value/use for C_4's could increase the competitiveness of this process.

NOVA also has a process covering the telomerization of butadiene with methanol, hydrogenation of the intermediate, then cracking to form octene-1 and methanol. They claim to have a better catalyst system, which uses a solid catalyst to avoid the costly procedures of recovering homogeneous catalysts and handling large volumes of organic solvents. They report selectivity to the desired intermediate of greater than 95 percent, with 60 to 85 percent conversion of butadiene. Using a commercially available catalyst for the cracking step, they report conversions greater than 65 percent with selectivity to octene-1 at greater than 96 percent. However, the lab scale tests were not fully successful in recovering the methanol.

4.2.4.3 Polystyrene - Syndiotactic

Syndiotactic polystyrene is a very promising polymer because of its excellent resistance to heat and chemicals. A drawback to syndiotactic polystyrene is its brittleness, limiting its applications and therefore limiting its market appeal.

There have been several extensive studies on the copolymerization of styrene with ethylene to improve the toughness of this material. However, attempts at producing a styrene-ethylene copolymer having syndiotactic styrene-styrene sequences were not successful.

4.2.4.4 Solution SBR - Batch Solution

Various butadiene based technologies to make SBR and BR through solution and emulsion routes (cold, hot) are understood to be getting renewed attention. Nexant will screen these to see if any deserve to be included in the valuations.

4.2.4.5 Adipic Acid - Butadiene Based

The butadiene hydrocarbonylation process shows an indicated 5 cents per pound of adipic acid savings in cash cost when compared to the next best process. A significant amount of development work remains to be done before the process is ready for commercialization.

4.2.5 Benzene and Toluene

4.2.5.1 Diphenymethanediisocyanate (MDI) - Diphenymethanediamine (MDA)

The carbonylation route has been demonstrated to work in laboratories but has not presently become a commercial technology. Because the carbonylation technology has removed the use of toxic phosgene gas, HCl, and NaOH, it is an improvement over the phosgene technology route. However, there are some barriers that the carbonylation route that prevent commercialization. Firstly, the process uses CO in place of hydrogen to reduce the nitro group. Because CO is more expensive, there is no material savings. In addition, carbonylation of nitrobenzene to carbamate requires high pressure vessels and equipment, making it even more expensive. It also requires the use of expensive metal compounds or toxic materials for catalysts. Lastly, the recycle of unconverted CO to high pressure reactor requires energy which also increases the economics of the process. Due to these difficulties, the carbonylation technology offers little advantage over a phosgene technology.

4.2.5.2 Diphenymethanediisocyanate (MDI) - Non-phosgene Based Routes

There has been development of the MDI process as a non-phosgene process on a pilot basis but the process has not yet been commercialized. With further improvements in technology and economics, the process shows much potential.

4.2.5.3 Caprolactam - Co-product Route from Adiponitrile (ADN)

Technology is unclear.

4.2.5.4 Adipic Acid - Direct cyclohexane Oxidation

The direct oxidation of cyclohexane to adipic acid is a process which has been explored for a long time. This is because of the advantages there would be when converting the cyclohexane into adipic acid in a single step without using an oxidizing agent such as nitric acid. There has been research performed allowing the one-step oxidation process of cyclohexane with industrially accepted selectivity, however, there is no solution which is industrially applicable to the processing of the reaction mixture obtained from the oxidation. Improvements in technology have to be made before the process can be commercialized.

4.2.5.5 Adipic Acid - Hydrogen Peroxide Oxidation - Cyclohexane

When compared to the air oxidation of cyclohexane, oxidation with hydrogen peroxide offers reduced reaction temperature and greatly reduced pressures. However, this process is costly due to the oxidizing agent used.

Studies have claimed efficiency to be higher than 90 percent. However, the specifics of the reaction conditions are given. There are also claimed advantages including not using organic solvents and halogen compounds due to the risk of environmental pollution and having only water as a byproduct. In order for this process to be economically viable, hydrogen peroxide would need to be produced at low cost.

4.2.5.6 Toluene Diisocyanate (TDI) - Non-phosgene Based Routes

Non-phosgene routes to produce isocyanates have been topics of interest to researchers for decades. Despite a few successful attempts at producing specialty isocyanate products with unique chemistry molecules, there has been no significant application of a non-phosgene process to produce TDI.

There has been some research performed that indicates there is a non-phosgene route that can be used to produce isocyanates and could be applicable for conversion of TDA to TDI. However, there needs to be more development and research work conducted before this process can be considered for commercialization.

4.2.6 BIOTECH

4.2.6.1 Acetic Acid – new biotech routes

There have been anecdotal reports of innovative biotech routes to produce acetic acid. It seems logical that the longstanding traditional fermentation sugar/alcohol route could be improved through modern bio methods, and acetic acid represents a high-volume global commodity chemical product in its own right. The conventional process via carbonylation of methanol continues to be dominant in the global industry, although SABIC’s ethane oxidation route has now been demonstrated.

4.2.6.2 Ethanol – from Biomass/Cellulosic Materials

The currently available and generally commercial technology uses sugars and starches as the key raw material, but breakthrough developments are being researched, such as various routes starting with cellulosic materials and other BTL concepts.

4.2.6.3 Ethanol – from Anaerobic Bacterium

An interesting prospective technology is the production of ethanol from synthesis gas via anaerobic bacteria. We understand that BRI Energy (Arkansas, U.S.A.) has been studying this at a pilot plant stage. The synthesis gas could conceptually be made from biomass or conventional methane reforming.

4.2.6.4 Biodiesel – New Processes

The currently available and commercial technology has significant limitations, but new breakthrough technologies are being sought.

4.2.6.5 1,4-Butanediol /THF - Biotech Route

A technology that is of high interest is a new process route that produces BDO from glucose via biotransformation through fermentation with a genetically modified Escherichia coli strain to succinic acid. The succinic acid is then hydrogenated to BDO.

The technology to be able to convert glucose derived from corn into succinic acid with a high yield fermentation process is feasible and can be integrated with hydrogenation to butanediol and derivatives. However, due to the questionable performance of the chosen organism and the electrodialysis module, the process may not be economically viable due to its inability to compete in the market.

The development goals are to reduce the reaction time and improve yield with ultimate gains in production capacity for a fixed investment.

4.2.6.6 Propylene Glycol - Catalytic Process from Glucose (Wheat)

Research is still being conducted involving the catalytic process of glucose to propylene glycol. The goal in the research is to develop economic methods to recover starch from mill feed and convert the starch to value-added chemicals. Also being evaluated is the value of the residual mill feed after starch removal.

The starch acquired from the mill feed can then be either fermented into lactic acid or converted through a catalytic process to produce propylene glycol. If a pilot proves successful, a commercial facility can then be designed and analyzed to see if the process is economically viable before commercialization.

4.2.6.7 Propylene Glycol - Catalytic Process from Sorbitol Acid (Corn)

Glucose from corn wet milling will be hydrogenated to form sorbitol and then new catalytical processes will be used to derive propylene glycol. These new catalytic processes need to be developed before further progression towards commercialization.

4.2.6.8 Propylene Glycol - Catalytic Process from Lactic Acid (Corn)

Glucose from corn wet milling could also potentially be fermented to produce lactic acid. After fermentation, new catalysts will be developed to derive propylene glycol. Again, these new catalysts will have to be developed before any further progression.

In addition to saving energy, the new catalytic process significantly lowers emissions of carbon dioxide, sulfur dioxide, nitrous oxides, volatile organic compounds (VOCs), and particulates compared to conventional petrochemical processes.

4.2.6.9 Polyols - Fractionation of Corn Fiber

An innovative new technology is being developed to cleanly and selectively remove hemicellulose from the corn fiber. Afterwards, the process would separate and isolate the xylose and arabinose fractions. Polyols (propylene glycol and ethylene glycol) would be derived using catalytic conversion from the xylose and arabinose.

4.2.6.10 Polyaldehyde - Hydroformylation of Soybean Oil

Studies are being performed on developing polyaldehyde through hydroformylation of soybean oil using two types of rhodium catalysts.

4.2.6.11 Ethyl Lactate - Fermentation of Sugars from Rice Straw

Studies are conducted to produce ethyl lactate from the fermentation of sugars derived from waste rice straw or other biomass. Lactic acid producing micro-organisms will be examined for carrying out separate hydrolysis and fermentation, as well as simultaneous saccharification and fermentation. This process claims to use 90 percent less energy than conventional.

4.2.6.12 Methyltetrahydrofuran (MTHF) - from Cellulosic Material Using Levulinic Acid

Technology unclear, but will be checked when we begin the work to decide if it is sufficient to warrant inclusion in the detailed valuation study.

4.2.6.13 Delta-Amino Levulinic Acid (DALA) - From Cellulosic Material Using Levulinic Acid

Technology unclear

4.2.6.14 Polylactide

Polylactide, (i.e., polylactic acid) ("PLA"), is a biodegradable thermoplastic aliphatic polyester derived from agricultural sources, such as corn starch or sugarcane. The chemical route to polylactide starts with bacterial fermentation to produce lactic acid, using corn starch or cane sugar as the principal raw material. The lactic acid is then oligomerized and dimerized catalytically to make the lactide monomer. PLA of a high molecular weight is produced by subjecting the monomer to ring-opening polymerization using a catalyst, typically either stannous octoate or tin (II) chloride, the latter typically in laboratory situations. Due to the chiral nature of lactic acid, several different forms of polylactide exist, including PLLA (the poly L-lactide from polymerizing L,L-lactide), and PDLA (poly-D-lactide). Blends of the two appear to offer the best combination of properties including temperature stability.

4.2.7 Other Chemicals

4.2.7.1 Hydrogen Peroxide - Direct Reaction of Hydrogen and Oxygen

The process for the direct reaction of hydrogen and oxygen poses a great challenge in the catalysis and process design. Because the reaction incorporates the use of oxygen in an acidic aqueous solution, usually containing halide, there is an issue of halide ions remaining in the peroxide product.

Additionally, the process also has potential runaway/side reactions decreasing the production of hydrogen peroxide from the reaction. The concentration of hydrogen peroxide produced is generally low at practical selectivities. And because of the low concentration of hydrogen peroxide produced there is an increase in economics for both capital and utilities. Also, the presence of potentially volatile halide could require specialty materials for columns as well as the reactor, further increasing the cost of this process. Attempts to overcome these difficulties with catalysts containing immobilized halide and with solid acid catalysts have resulted in very low peroxide concentrations.

In addition, oxygen represents a significant cost item in this process.

4.2.7.2 Biodegradable Polymers - Polycaprolactone/Polybutylsuccinate

Technology unclear, but with current petrochemical prices, there is thought to be an increasingly favorable market environment for such new technologies.

4.2.8 Fuels

4.2.8.1 Methane to Fuels

A number of companies are believed to be doing research on the direct conversion of alkanes to heavier hydrocarbons useful for fuels, which might include gasoline and middle distillates. For instance, in March 2009 a U.S. patent was issued and assigned to Marathon Oil for converting gaseous alkanes to liquid hydrocarbons. The process involves reacting the alkanes with bromine to form alkyl bromides and hydrobromic acid vapor. The mixture of alkyl bromides and hydrobromic acid are then reacted over a synthetic crystalline alumino-silicate catalyst so as to form higher molecular weight hydrocarbons and hydrobromic acid vapor. Propane and butane which comprise a portion of the products may be recovered or recycled back through the process to form additional C_5+ hydrocarbons, while methods are disclosed to separate the hydrobromic acid vapor and the heavier hydrocarbons.

We understand that Marathon has been actively researching a "GTF" (gas to fuels) technology for potential demonstration or commercialization that may utilize a technology such as this.

4.2.8.2 Innovative GTL Technology

A number of firms are developing or commercializing innovative GTL (gas to liquids) technologies, involving the two key GTL steps – the production of synthesis gas and the Fischer-Tropsch reaction to form the fuel products. These include, for example, CompactGTL and Velocys/Oxford Catalysts.

CompactGTL is a technology company focused on developing GTL technology for associated gas. They have developed and are in the process of demonstrating in a pilot or pre-commercialization step their own compact reactor technology. Their intention is to use their technology to enable the gas produced in oilfields to be converted easily and economically to synthetic crude oil. The technology on which they are working combines the two stages of the GTL process into one integrated system that is intended to give high levels of volumetric efficiency and other favorable attributes. Their process combines steam methane reforming, syngas conversion by FT synthesis, tail gas recycled as fuel, and waste water recycled to feed the reforming step.

The Velocys technology is based on innovative microchannel reactors, which have large numbers of parallel and/or perpendicular microchannels. These microchannel reactors enable the use of significantly more active catalysts than can be utilized by conventional reactors. They can result in substantial capital cost savings, improved product yields, and greater energy efficiencies than conventional technologies, particularly when incorporated into smaller scale projects such as those suited to BTL (biomass to liquids) and to GTL using flared or associated gas as well as small to medium scale stranded methane gas, a potentially significant addressable market.

4.2.8.3 Tar Sands Bitumen Upgrading

The rise in energy and petroleum prices during 2004 – 2008 inaugurated renewed interest in developments related to the Athabasca Tar Sands. This immense resource, combined with serious challenges in terms of capital costs and operating costs needed to recover and utilize the bitumen contained in the tar sands, have spurred a number of innovative technology efforts. Some of the key firms working on these include Genoil, ETX Systems, Ivanhoe Energy, Chevron, ENI/Snamprogetti, and Northern Oil Research Technologies, among others as well. The key goal is to achieve an acceptable level of conversion to a usable or shippable liquid synthetic crude oil or petroleum products while minimizing capital and other costs, and in some cases minimizing the consumption of water in the processing. Nexant proposes to include a typical such technology in the ones to be studied, assuming that sufficient information is available when the study is done to allow such a typical case.

The following 24 technologies were considered highly prospective and for them we modeled their costs of production and estimated their values by using the Licensing business model, and the results are documented in the report.

Acetic Acid via anaerobic batch fermentation	Methanol via oxidation of methane
Acrylic Acid via direct oxidation of propylene	MDI (isocyanate) via conventional phosgenation
Acrylonitrile via propane amoxidation with oxygen	Octene-1 via ethylene tetramerization
Adipic Acid via butadiene carbonylation	Octene-1 via butadiene telomerization / hydrogenation
Adipic Acid via cyclohexane air oxidation	Propylene via MTP
Biodiesel via heterogeneous catalysis	Propylene via methathesis
Caprolactam ex butadiene via aminocapronitrile	Propylene Oxide via HPPO
Ethanol via photosynthesis of carbon dioxide by algae	PTT via propanediol
Ethylene via Asahi catalytic pyrolysis	SBR-solution via typical solution process
Ethylene via ethane dehydrogenation	Styrene via methanolysis of toluene
Hydrogen Peroxide via direct synthesis	Synthetic crude oil via small scale GTL
Methane via photocatalytic reduction of carbon dioxide	TDI via dimethyl carbonate (non-phosgene route)

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7.1 GENERAL

Nexant uses multidisciplinary project teams drawn from the ranks of our international staff of engineers, chemists, economists and financial professionals, and from other Nexant groups to respond to the requirements of each assignment. Most of the staff of consultants possess credentials in both scientific and commercial disciplines plus substantial industrial experience. The collective talents of our staff, strategically located and closely linked throughout the world, result in valuable insights gained through a variety of perspectives.

Chem Systems is an international consultancy that is now part of Nexant, Inc., and is dedicated to assisting businesses within the global energy, chemical, plastics and process industries by providing incisive, objective, results-oriented management consulting. Over three decades of significant activity translate into an effective base of knowledge and resources for addressing the complex dynamics of specialized marketplaces. By assisting companies in developing and reviewing their business strategies, in planning and implementing new projects and products, diversification and divestiture endeavors and other management initiatives, Nexant helps clients increase the value of their businesses. Additionally we advise financial firms, vendors, utilities, government agencies and others interested in issues and trends affecting industry segments and individual companies. Whether identifying opportunities, managing change or confronting competitive challenges, we adhere to the highest ethical and professional standards.

Chem Systems, founded in 1965, was an independent, management-owned consultancy until IBM acquired it in 1998, and from 1998 until mid-2001 Chem Systems was a part of IBM Global Services and IBM's Chemical and Petroleum Group. In late 2001 the Chem Systems unit of IBM was acquired by Nexant, Inc. Nexant, Inc. is an independent industry-expert consulting firm, spun off from Bechtel in 2000, that provides technology solutions and experienced-based technical and management consulting services to electric utilities, energy producers, chemical companies, oil and gas companies, governments, and energy end-users worldwide. All of the staff and intellectual capital of Chem Systems were acquired by Nexant, Inc. Thus, Nexant, Inc. continues to maintain fully-integrated operations in White Plains, New York; London, England; San Francisco, California; and Washington, D.C. Other business unit offices are located in Boulder, Colorado and Phoenix, Arizona, and affiliate businesses and Nexant offices are located in Tokyo, Bangkok, Beijing, Shanghai, Seoul, and Houston. We also work with representatives throughout the world.

From major multinationals to locally-based firms and governmental entities, our clients look to us for expert judgment in solving compelling business and technical problems and in making critical decisions. The acquisition of Chem Systems by Nexant, Inc., in 2001 enhanced Chem Systems' ability to successfully serve its clients. That merger's success resulted from complementary methodologies and technologies, which are used to provide services to clients and allow us to provide more complete and effective consulting.

Nexant's clients include most of the world's leading oil and chemical companies, financial institutions, and many national and regional governments. Nexant, Inc. is active in most of the industrialized countries of the world, as well as in most of the developing areas including the Middle East, Africa, and East and Southeast Asia.

Major annual programs are:

- Process Evaluation/Research Planning® (PERP)
- Petroleum and Petrochemical Economics (PPE)/*ChemSystems* Online® (CSOL) – United States, Western Europe and Asia Pacific

The PERP service covers technologies, both proven and prospective in the chemical and energy industries. The program has more than 50 subscribers, including most of the major international chemical and petroleum companies.

PPE/CSOL covers the market and manufacturing economics for major petrochemicals.

Over the past five years, the PPE/CSOL program has been completely overhauled and upgraded. The models and databases that run the analysis have been replaced with a start-of-the-art industry simulation program that has taken the 30 years of industry knowledge and experience of our consultants and enhanced it to a proved new level of forecasting expertise.

Our Proprietary simulation model is used to generate the PPE reports and also an internet serviced brand *ChemSystems* Online® that provides global data, analysis, and forecasts of:

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- Consumption
- Supply/demand and trade
- Profitability analysis
- Forecast
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7.2 SUMMARY OF PROJECTS RELATED TO TECHNOLOGY VALUATION

7.2.1 Commercial Analysis

Nexant's annual PPE (Petroleum and Petrochemical Economics) subscription program provides a core of data and analysis for Nexant's commercial consultancy. Covering the refining, commodity petrochemical and polymer industries, the PPE program includes consumption, supply, trade, pricing, and margins. Price forecasts are developed from extensive knowledge of price-setting mechanisms and of supply industry structure.

Multiclient activities such as PPE account for a minor proportion of Nexant's consultancy. Most of our work consists of singly commissioned assignments for commercial clients, ranging from customized market research through to strategic consultancy on business positioning. Nexant's commercial analysis experience extends from oil and gas, petrochemicals, gas-based chemicals (including fertilizers), inorganic commodities through to fine and performance chemicals. Within our financial client base, we are regarded as highly credible in commercial analysis. Our commercial analysis work provides a strong insight that is also used in our work on technology assessments.

7.2.2 Technology Valuation

Assessment of technology is the other foundation of Nexant's consultancy. In multiclient programs such as Chem Systems' PPE and POPS (PolyOlefin Planning Service), Nexant analyses the cost-competitive position of different process technologies and their potential for product differentiation. We use our methodology to track and forecast industry profitability using Leader and Laggard plant models.

Nexant reviews emerging as well as conventional process technologies in its Chem Systems' PERP (Process Evaluation, Research Planning) program. The analysis ranges from development of conceptual designs from patents for new processes to critical review of licensor or operator data on processes in the early stages of commercialization, with the goal of the analyses in the PERP program typically being comparisons of the costs of production among competing technologies. Our new study on *New Technology Valuations* will build on and extend from our technology assessment work in PERP and our single-client technology valuation work experience.

Most of our technology evaluation projects are singly commissioned. We have evaluated the position and prospects for owners of technology developments, and have advised purchasers and sellers of process technology on the licensing strategy and value. For financial clients, we have assessed risks associated with innovative one-of-a-kind technologies. Our work also includes benchmarking and due diligence assignments, which provide practical background knowledge of real plant operations and cost structures (but specific data are not revealed to third parties).

For technology evaluation also, Nexant is regarded by financial clients as highly credible.

7.3 SELECTED SAMPLE OF SINGLE CLIENT TECHNOLOGY VALUATION ENGAGEMENTS

7.3.1 Assessment of Technology Values

- For a number of well-known private equity firms, Nexant was engaged in over ten engagements over the last two years to conduct independent technology audits and valuations of technologies that were confidentially owned and that were being considered for acquisition.
- For a private equity firm seeking to analyze a potential major investment in the global inorganic acid industry, Nexant was engaged to perform the role of technical consultant with the key issue being the technological strength and the business reliability of the target company's technology offering.
- For a major engineering and technology company, Nexant was engaged to develop independent valuation of the technologies of a major technology licensing firm that was available for acquisition. Nexant's work was a key input to the client making a competitive bid for the target company without overpaying.
- For a number of major chemical and energy project investments being planned in the Asia Pacific region over the last three years, Nexant has been engaged by project developers to help it select the technologies to be licensed for their projects.

7.3.2 Assessment of Technology and Technical Risks

- For Dalian Shide, a joint venture group interested in developing a petrochemical project in North-Eastern China, Nexant reviewed and ranked a comprehensive group of chemical process technologies, as to their reliability and suitability to be licensed for their prospective project.
- For a major well know private equity firm, Nexant performed a technology and commercial assessment of a major acquisition in the petrochemical and specialty chemical industry.
- For a major U.S.-based EPC and process technology firm, Nexant performed a comprehensive due diligence and valuation advisory engagement as part of our client's bidding on a major process technology firm's acquisition.
- For a number of private equity and operating firms (such as Bain Capital, Oaktree Capital, Court Square Capital, Kohlbeg & Co., Blackstone, Apollo, etc.), Nexant has performed valuations of both developing or proven chemical process technologies, from the perspective of a technology licensor and an operating company.
- For Pegasus Capital, Nexant performed a due diligence review and valuation of the fertilizer operations of Coffeyville Resources, including an assessment of the technical merits and risks in its gasification technology and plant.
- For the lead bank on behalf of the U.S. ExIm Bank and other Banks financing the Cilacap Refinery Debottlenecking Project, Nexant performed a technical review of the modifications and technology being employed for the project.

- For Acetex Corporation, Nexant performed a technology, commercial, and valuation study in its acquisition of AT Plastics, a firm in the LDPE resin and film business.
- When Texaco Chemical was selling its propylene oxide technology and business in latter 1990s, Nexant was engaged by a leading private equity bidder to assist it in assessing and valuing the technology. When the auction was one by a strategic investor, Nexant was then engaged by the winning bidder to provide an assessment of the business and technology for the purpose of providing opinions to lenders.
- For the Coordinator of the Club of Banks financing the Singapore Aromatics Project, Nexant was retained as Independent Engineer Consultant and performed a technical review of the plant design. This included review of the process configuration and technology employed, feedstock design basis and flexibility, plant capacity and debottlenecking infrastructure and integration with the adjacent refinery, technology license agreements/guarantees by licensors/ contractors.
- For a New Zealand consortium, Nexant conducted a technical audit and evaluation of Mobil's methanol-to-gasoline process. This was the first commercial application of this technology. As such, it was necessary to thoroughly review all the R&D development, pilot plant, and scale-up design work upon which the commercial design was based to assess and provide some comfort to prospective lenders on potential technical risks. Nexant’s report was included in the Information Memorandum used for the $1.7 billion project financing.
- For a Thai aromatics company, Nexant carried out a review and audit of the original process configuration and made recommendations for improvements to the process configuration. This included feedstock flexibility considerations based on most likely sources.
- For the Chase Manhattan Bank, NA, on behalf of the arranging banks, Nexant carried out an assignment evaluating a number of technical and commercial issues relating to the Rayong Refinery Company project in Thailand. This assignment included a detailed technical evaluation of the process, technology, capacity, and project sensitivities. ABN AMRO is familiar with this work.

7.4 SYNTHETIC GAS AND COAL UTILIZATION TECHNOLOGIES ANALYSES EXPERIENCE

- **CHEMICALS FROM COAL AND SHALE FEEDSTOCKS --** Recognizing the eventual importance of coal and shale resources in replacing gas and petroleum, this study examined the various technologies that could be used to produce feedstocks and chemicals. Three separate potential implementation cases were treated in detail: Economic, By-product, and "National Need." The production of synthetic fuels, olefins, and aromatics and their derivatives from coal and shale were projected through the year 2000. A large number of patent references and flowsheets are included in the study, which also reviewed the chemical implications of synthetic fuels programs in the United States and elsewhere. There is also a section on utilization of U.S. tar sands resources.

- **SYNTHESIS GAS (FUTURE SOURCES)** -- This report reviewed the technology for production of synthesis gas (H_2, 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.

- **HYDROGEN-SYNTHESIS GAS STUDY** -- Nexant completed a multiclient study on the production of hydrogen and synthesis gas from heavy oils and coal. The objective of this study was to analyze the effects on the U.S. natural gas shortage on that portion of the petrochemical industry dependent upon natural gas as a feedstock, with particular emphasis on ammonia, methanol, and hydrogen-based chemicals. The study included a section on comparative costs for all hydrocarbon feedstocks from natural gas to coal.

- **WEST GERMAN COAL RESEARCH AND DEVELOPMENT/COAL GASIFICATION** -- West German companies have undertaken a massive effort to update their technologies to meet motor fuels and chemical requirements from indigenous and imported coals. An unusually productive marriage of government and private money, deployed in pilot plants located in chemical and energy complexes, is steadily advancing the state of the art in West Germany. Promising United States technologies are also being considered and improved. This study reviewed and analyzed the individual programs for their merit and impact on synthetic fuels and coal-based chemicals projects in the industrialized countries.

- **EVALUATION OF COAL BASED AMMONIA/METHANOL PROJECT** -- Nexant developed the overall facilities concept and developed capital cost estimates for this project. Lurgi and Koppers-Totzek gasifiers were studied in detail. Internal steam and power balances were developed and the optimal synthesis gas processing sequence was developed.

- **EVALUATION OF COAL/NATURAL GAS BASED METHANOL/POWER** -- Nexant developed the overall facilities concept and capital cost estimates for an integrated complex employing "second generation" coal gasification, steam/methane reforming and combined cycle power generation technologies for the co-production of methanol and power. Relative coal and natural gas consumption was based on producing a stoichiometrically balanced methanol synthesis gas from coal-based hydrogen deficient and natural gas based carbon deficient synthesis gases.

- **COAL TAR CHEMICALS** -- In response to a Japanese company's request for an analysis of coal tar chemicals, Nexant conducted a study of U.S. and West European markets/applications and evaluated the technology for four basic coal tar chemicals and specific hydrogenated derivatives. The compounds studied included tetralin, biphenyl, acenaphthene, phenanthrene and hydrogenated derivatives of acenaphthene and phenanthrene. The technology review covered all aspects of the chemistry of these materials as well as all applications and developments worldwide.

- **IMPACT OF COAL CONVERSION PLANTS ON AROMATICS** -- For a U.S. chemical company, Nexant assessed the economic feasibility of aromatics recovery from by-products streams of coal gasification and coal liquefaction plants. Production technology and economics are provided for benzene, toluene, phenol, cresol, xylenol, and coal derived naphtha.

- **SMOKELESS FUELS FROM COAL** -- For a specialty fuel producer, Nexant identified and characterized methods for producing smokeless briquettes that met international standards and identified potential binders that could be used with existing equipment to produce smokeless briquettes that could be used for export. Binders studied included: coal tar pitch, petroleum resin, coal and starch.

- **MARKETING ASSESSMENTS OF COAL PRODUCTS/BY-PRODUCTS** -- Nexant, under contract to Tri-State Synfuels Company (a partnership between Texas Eastern Synfuels Inc. and Texas Gas Synfuel Corporation) examined in detail the marketability of products from a Lurgi/Fischer-Tropsch coal-based facility being considered for Henderson, Kentucky. The coal conversion facility was being evaluated by Tri-State under a cooperative funding agreement with the U.S. Department of Energy. The products from the plant included high Btu substitute natural gas (SNG) liquid transportation and heating fuels, and a wide range of chemical products and by-products. Nexant analyzed the general eight-state region surrounding the proposed plant. Recommendations and observations were made relating to possible changes in the originally envisioned slate of products that might improve the project's revenue generation capability. Future product prices and values were forecast, based on Nexant's prevailing long-term prognosis of energy, petroleum and petrochemical demands. Nexant performed two similar market analysis studies for New York Power Authority (NYPA). One involved a proposed 600 MW coal gasification combined cycle power plant considered for the Buffalo area. Nexant analyzed current and future markets for the fuels and chemicals (including synthesis gas derivatives) that could be manufactured in the complex. The second study was for a coal gasification plant being evaluated by NYPA for the South Bronx. Products considered for this plant included medium-Btu gas (and potential products) steam, sulfur, carbon dioxide and industrial gases (oxygen, nitrogen and argon).

- **VALUE OF COED PROCESS COAL-DERIVED LIQUIDS IN A PETROLEUM REFINERY** -- This study analyzed the value of liquids produced in a plant designed to make synthetic crude oil from coal.
- **VALUE OF LIQUIDS PRODUCED FROM COAL IN A COG (COAL, OIL GAS) REFINERY** -- This study, for the Pittsburgh & Midway Coal Mining Company, determined the value of coal-derived liquids in petroleum refineries.
- **COAL-METHANOL SLURRY PREFEASIBILITY STUDY** -- This study analyzed the economic viability of using coal-methanol slurry fuels in Malaysia.
- **COAL-LIQUID MIXTURE** -- Assistance was provided to the U.S. Synthetic Fuels Corp., on oil, water and methanol coal mixture technologies, economics and markets in regard to defining the scope for a planned solicitation.
- **COAL MINE ASSETS APPRAISAL** -- Certain coal mining equipment (mobile and fixed) and systems were evaluated and appraised in support of a lease financing.
- **EVALUATION OF COAL TO SYNTHETIC GASOLINE PROJECT** -- This project compared the attractiveness of gasoline production from coal derived methanol via the Mobil MTG (methanol-to-gasoline) process, to the economics of direct coal liquefaction as well as coal based methyl fuel production.
- **CHEMICALS FROM COAL AND SHALE** -- This study was performed under an RANN grant by the Office of Energy R&D Policy, NSF. The objectives of this study were: estimate feedstock demands for major organic chemicals through the year 2000; gauge the probable timing as to when chemical feedstock demands will constitute an unreasonably large fraction of conventional hydrocarbon sources; identify the potential technologies for (a) transformation of coal and shale building blocks to primary organic chemical building blocks or feedstocks, and (b) synthesis of current "petrochemicals" from such coal and shale-derived building blocks; define research and development strategies and a related program to assure that any conversion of the organic chemical industry to coal and shale would be based upon available and the most economically possible technology.
- **SYNTHESIS GAS FOR CHEMICALS** -- This multiclient report dealt with the applicability of emerging synthesis gas based routes to chemicals compared to traditional production methods. The synthesis gas based routes were analyzed based on the economics of large-scale production of synthesis gas from coal.

7.5 ASSESSMENT OF BIO TECHNOLOGIES

7.5.1 Relevant Nexant PERP Program Report Studies

Relevant recent reports from this program include:

Ethanol –Analysis of fuel ethanol production by dry corn milling fermentation

Biodiesel – Including production technologies (commercial and developmental) and economics, feedstock issues, regulatory and market drivers, supply and demand

Glycerine – Comparison of the natural oil and synthetic-based production routes – considering production technologies, economics, feedstocks, and global markets

Methanol – Nexant has done a number of PERP as well as other Multiclient and single client reports on methanol and its derivatives.

Plants as Plants – A study of 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.

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.

Refinery of the Future as Shaped by Environmental Regulations – Reviews issues of supply and quality of crude oil feeds to refineries, trends in quality and volume requirements for refined products, and environmental drivers for both refinery operations as well as fuel specifications.

Biodesulfurization of Petroleum Fractions – Compares various versions of conventional refinery hydrodesulfurization with developments in fermentation based biodesulfurization.

7.5.2 Individual Client Studies

A partial list of relevant single client ("custom work") projects includes:

Global Biofuels Strategy - For a leading U.S.-based multinational firm grounded in the agricultural sectors, Nexant performed a comprehensive analysis comparing technological, supply chain, and geographic options for involvement in the biofuels sector.

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.

Chemicals from Corn – This is 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 considers a wide range of potential sugars, and fermentation-derived acids, alcohols, and other building blocks, but emphasizes 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.

Biodiesel Glycerine Byproduct - Market Dynamics – For a major U.S.-based multi-national 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. This subject was also addressed in two recent papers presented at international conferences.

Biobased Fuel Cells – At the BIO World Congress on Industrial Biotechnology and BioProcessing, Orlando, FL, April 20-22, 2005, Nexant presented a paper on biofuels use in fuel cells based on a study of Stationary Fuel Cells for Nexant's PERP program, and also chaired a panel on Bio-based Fuel Cells, which included discussions of enzyme-based fuel cell membrane and electrode technologies to utilize hydrogen or biofuels.

Ethanol vs. MTBE – Litigation Support – Nexant advised the U.S. Department of State in an action defending California against methanol interests for claims of losses in the phase-out of MTBE and use of ethanol as a substitute gasoline oxygenate. This work included a detailed analysis of the ethanol production and distribution infrastructure in the United States and addressing practical, environmental, safety and issues of using ethanol in gasoline.

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.

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 multi year 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.

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