Multiclient Prospectus

Chemicals from Acetylene

Back to the Future?

Nexant

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1.1 OVERVIEW

Nexant has developed a new multiclient study to analyze the technologies and economics of producing commodity chemicals and their derivatives from acetylene in light of acetylene's apparent renewed competitiveness as a viable feedstock to the chemical industry.

1.1.1 Overall Value Premise

Between 1960 and 1970, when worldwide acetylene production peaked, it served as the primary feedstock for a wide variety of commodity and specialty chemicals. Advances in olefins technology and concerns about acetylene safety, but mostly loss of cost competitiveness, reduced and effectively limited the importance of acetylene.

Now, with the current rise in petroleum prices, acetylene is finding a new place in the chemical industry. Conventional steam cracker feedstocks, be it from crude oil or refinery products, has continued to increase in cost versus the feedstocks for acetylene production, natural gas and coal. Additionally, technology advances in acetylene production, most notably from coal, coupled with the advantageous present and forecast coal prices globally, are enticing coal-rich countries to examine acetylene-based routes as viable alternatives to olefin derived chemicals.

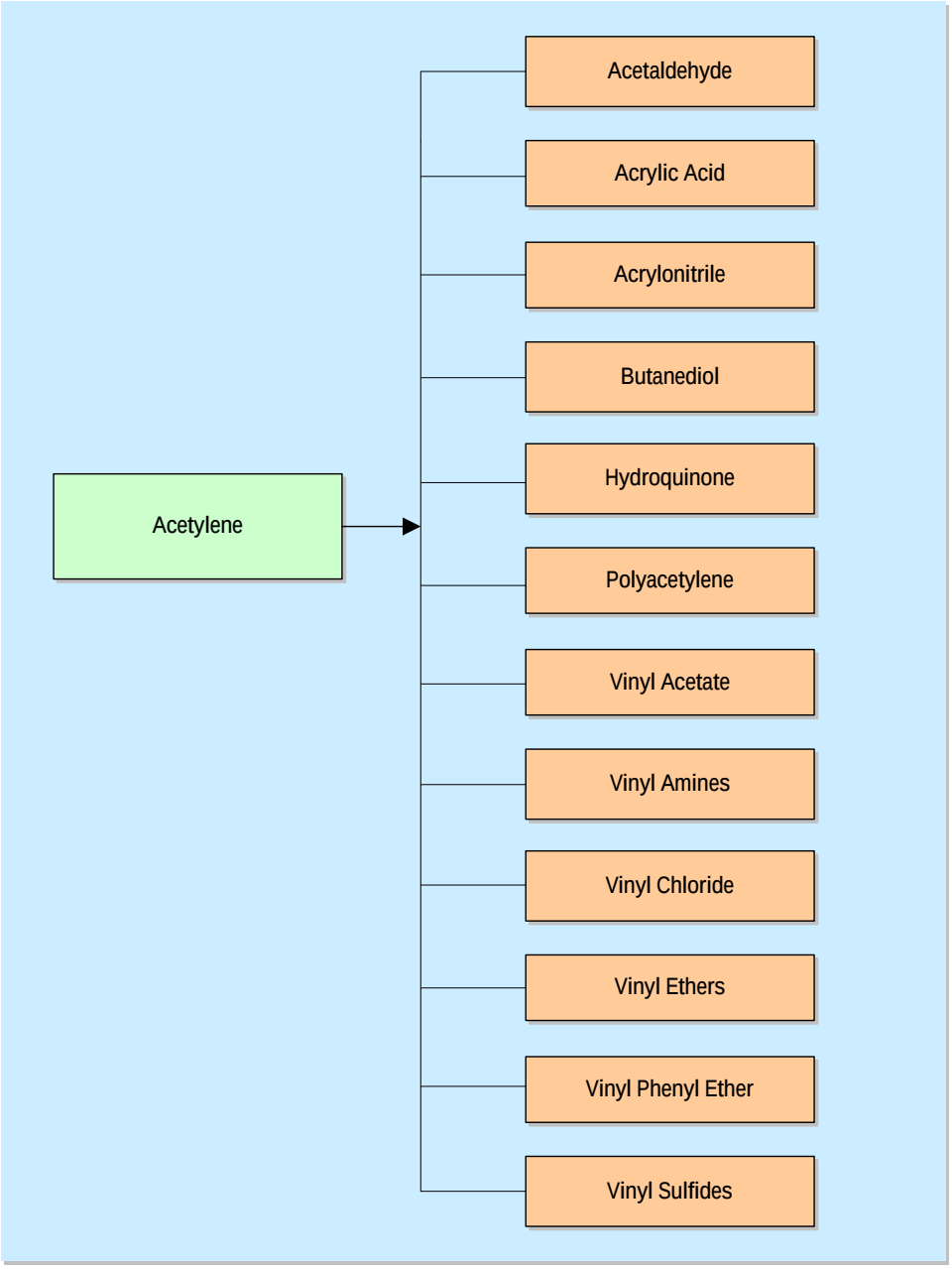
This prospectus describes the background of why renewed interest in acetylene is an important and timely issue, the scope of our analysis, and the approach we used in the study. We also detail our experience and qualifications to perform the study, and how you may subscribe.

1.2 BACKGROUND

Acetylene is the simplest member of unsaturated hydrocarbons called alkynes or acetylenes. In the first half of the 20th century acetylene was the most important of all starting materials for organic synthesis. Some of the products potentially produced from acetylene are shown in Figure 1.1. The usefulness of acetylene is partly due to the variety of additional reactions which its triple bond undergoes, and partly due to the fact that its weakly acidic hydrogen atoms are replaceable by reaction with strong bases to form acetylide salts.

However, acetylene was largely replaced by olefin feedstocks, such as ethylene and propylene, because of its high cost of production and the safety issues of handling acetylene at high pressures. Its use has largely been eliminated, except for the continued, and in some instances, growing production of vinyl chloride monomer (principally in China), 1,4-butanediol, and carbon black. Up until the 1970s, acetylene was a basic chemical raw material used for the production of a wide range of chemicals, as shown in Figure 1.2.

Figure 1.1 Acetylene Products



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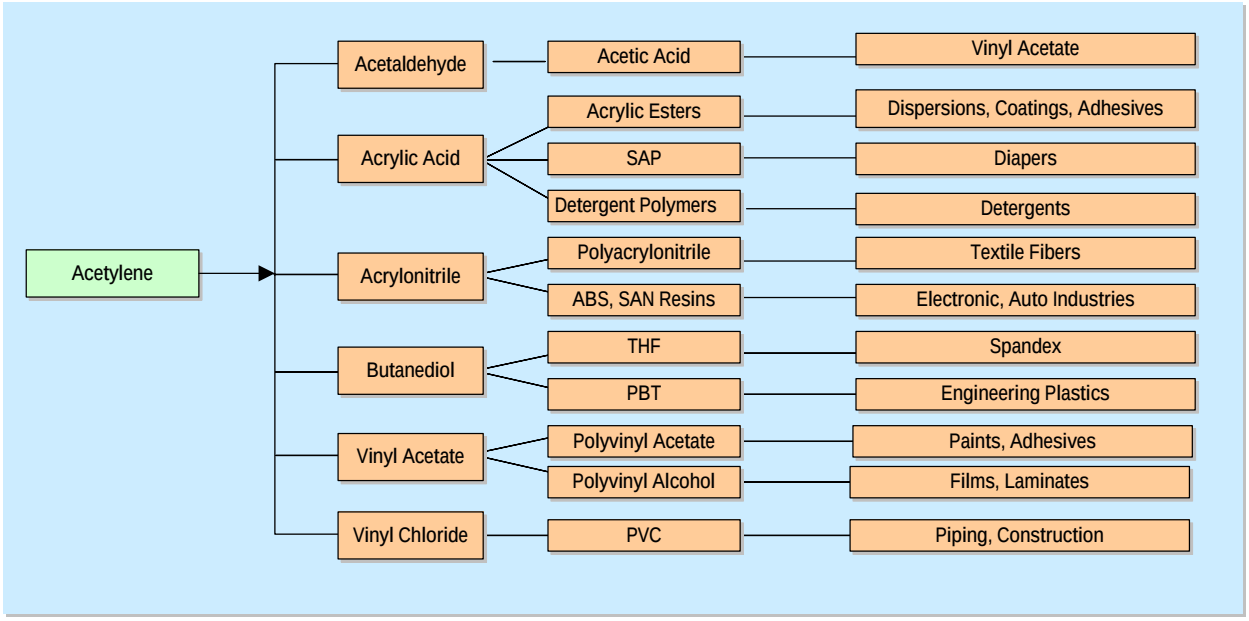
This product profile can be shortened to a list of commercially important chemicals and their principal derivatives and applications, as shown in Figure 1.2.

Figure 1.2 Commercial Derivatives



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In addition, though not historically commercially pursued for reasons of economics, acetylene can theoretically be used to produce benzene (via acetylene cyclotrimerization) and ethylene (via acetylene hydrogenation), though acetylene hydrogenation is practiced generally as part of a typical ethylene cracker to remove acetylene impurities.

The large-scale production of benzene and ethylene from acetylene might be competitive if acetylene can be produced cheaply enough and might prove to be a viable alternative going forward.

Acetylene is produced from several main processes and feedstocks. Hydrocarbons are the major feedstocks in the United States and Western Europe, either in the form of natural gas in partial oxidation or as byproducts in ethylene production. However, coal is becoming an ever increasing source of acetylene in countries with plentiful and cheap coal supplies, such as China, for the production of VCM. This source of lower cost acetylene may prove to be the impetus for returning acetylene to its place as a major chemical feedstock, especially in light of current and projected high oil prices and improvements in the safety, cost and environmental protection of the calcium carbide process for the production of acetylene.

Certainly, acetylene to VCM for production of PVC has become the most commercially important re-emerging acetylene use. The access to cheap coal, along with improvement in technology both from cost and emissions standpoints, has made this a favored route in China, especially when considering the short supply of ethylene from traditional steam cracking. China has an abundance of coal and limestone resources, is lacking in ethylene supply and oil resources, and has a long history in the production of coal-coke-calcium carbide-acetylene-

VCM. China has an abundance of experience in this area and has done a significant amount of research and development work in process technologies and equipment. The recent oil price flyup has further stimulated R&D and project interest and initiation.

With a growing concern for pollution, low resource utilization rate and overall competitiveness, the Chinese government is paying greater attention to these issues, and new rules and regulations have been enacted to restructure the industry there and close the unqualified small coke furnaces. A new plant standard was issued by the NDRC (National Development and Reform Commission of the People's Republic of China) in December 2004, regulating the conditions for new projects and expansions. NDRC also issued a standard for new calcium carbide entrants at the same time as the coke regulations.

These technology advances as practiced in China have demonstrated that acetylene, in this case from coal, is a viable and competitive option for chemicals production.

1.3 ABSTRACT

The resurgence of the use of acetylene for chemicals production will depend upon the relative cost of acetylene versus the more commonly used feedstocks. The technologies for the chemicals production are well known and have been improved since the heyday of acetylene. More importantly, the process technology to produce acetylene has been greatly improved and optimized, and now can offer attractive competitiveness in the right situations.

Acetylene is produced via four commercially practiced processes:

- The classic commercial route to acetylene, first developed in the late 1800s, is the calcium carbide route in which lime is reduced by carbon (in the form of coke) in an electric furnace to yield calcium carbide. During this process a considerable amount of heat is produced, which is removed to prevent the acetylene from exploding. This reaction can occur via wet or dry processes depending on how much water is added to the reaction process.

  The calcium carbonate is first converted into calcium oxide and the coal into coke. The two are then reacted with each other to form calcium carbide and carbon monoxide:

  $$CaO + 3C \longrightarrow CaC_2 + CO$$

  The calcium carbide is then hydrolyzed to produce acetylene

  $$CaC_2 + 2H_2O \longrightarrow C_2H_2 + Ca(OH)_2 \quad H = 129\ kJ/mol$$

- Partial oxidation of natural gas

  Acetylene can also be manufactured by the partial combustion of methane with oxygen. The process employs a homogeneous gas phase hydrogen halide catalyst other than hydrogen fluoride to promote the pyrolytic oxidation of methane. The homogeneous gas

phase catalyst employed can also consist of a mixture of gaseous hydrogen halide and gaseous halogen, or a halogen gas.

- Electric arc or plasma pyrolysis of coal

  This arc coal process involves a one megawatt arc plasma reactor which utilizes a DC electric arc to generate and maintain a hydrogen plasma. The coal is then fed into the reactor and is heated to a high temperature as it passes through the plasma. It is then partially gasified to yield acetylene, hydrogen, carbon monoxide, hydrogen cyanide and several hydrocarbons.

- As a byproduct of ethylene steam cracking

The use of acetylene as a commodity feedstock decreased due to the competition of cheaper, more readily accessible and workable olefins when these olefins were produced from low cost petroleum products. With the rising cost of crude oil, natural gas, and the associated olefins feedstocks (such as naphtha, ethane, propane, etc.) the olefins prices are no longer low enough to preclude the possibility of using acetylene. Additionally, regional shortages of these olefins and their feedstocks have forced the search for alternate routes to the commodity chemicals, such as the production of VCM in China from acetylene.

In the United States during the mid 1960s, more than 460 thousand tons of commodity and high volume chemicals were produced from acetylene, as seen in Table 1.1. By the mid 1970s, that figure had decreased to less than 200 thousand tons.

Table 1.1 U.S. Production of Chemicals from Acetylene[1]
(Thousand metric tons)

	1965	1974
VCM	159	59
Acrylonitrile	91	--
Chloroprene Rubber	82	--
VAM	64	32
Miscellaneous[2]	68	91

[1] Industrial Organic Chemistry, Weissermel and Arpe
[2] 1,4-BDO, THF, etc.

Historically, acetylene has been used to produce many important chemicals:

- ***Vinyl chloride monomer:*** Vinyl chloride monomer (VCM) was first produced by reacting acetylene with hydrogen chloride. Acetylene-based technology predominated until the early 1950s. Due to the high energy input needed in the acetylene-based process and the hazards of handling acetylene, the ethylene-based route has become the predominant one. However, the acetylene-based route does have its advantages. In China, where there is shortage of ethylene cracker feedstock, approximately 60 percent of VCM capacity is acetylene based. VCM polymerizes to form polyvinyl chloride (PVC)

which has numerous uses in the building and construction, transportation, electrical/ electronic, medical, packaging, and home and leisure arenas. The most important PVC markets worldwide are for building and construction applications, such as pipe/conduit/fittings, siding, gutters/downspouts, window profiles, etc.

- ***Acrylonitrile:*** Hydrogen cyanide added to acetylene produces acrylonitrile, used as an intermediate in the production of nitrile rubbers, acrylic fibers, and insecticides.
- ***Vinyl Acetate:*** Acetic acid added to acetylene forms vinyl acetate, used as an intermediate in polymerized form for films and lacquers.
- ***Vinyl Ether:*** Alcohol added to acetylene yields vinyl ether used as an anesthetic.
- ***Acetaldehyde:*** Water added to acetylene produces acetaldehyde used as a solvent and flavoring in food, cosmetics and perfumes.
- ***1,2-Dichloroethane:*** Chlorine added to acetylene forms 1,2-dichloroethene, used primarily as a feedstock for vinyl chloride monomer (VCM), which, in turn, is the monomer for the widely-used plastic, polyvinyl chloride (PVC). Lesser EDC uses are as feedstock for certain chlorinated solvents and the plastic, polyvinylidene chloride.
- ***1,4-Butynediol:*** Formaldehyde added to acetylene produces 1,4-butynediol, which is then hydrogenated to 1,4-butanediol and used as a chain extender for polyurethane. These resins include urethane foams for cushioning material, carpet underlay and bedding, insulation in refrigerated appliances and vehicles, sealants, caulking and adhesives.
- ***Acrylate Esters:*** Acetylene reacts with carbon monoxide and alcohol forming acrylate esters used in the manufacture of Plexiglass and safety glasses.
- ***Polyacetylene:*** Acetylene can polymerize forming polyacetylene. The delocalized electrons of the alternating single and double bonds between carbon atoms give polyacetylene its conductive properties. Doping of polyacetylene makes this polymer a better conductor. Polyacetylene is used in rechargeable batteries that could be used in electric cars and could also replace copper wires in aircraft because of its light weight.
- ***Polydiacetylene:*** Polydiacetylene is also a polymer of the future. It behaves as a photoconductor and could be used for time-temperature indicators or monitoring of irradiation.

Based on its availability, its many uses and prospective uses, acetylene is definitely an interesting possibility going forward, if available at competitive cost.

2.1 OVERVIEW

Nexant has examined and described the process routes for acetylene production and the derivatives of acetylene. We examined these technologies by reviewing and evaluating the processes and economics for the production of acetylene and for the principal commodity derivatives of acetylene. For acetylene production, we included the major commercial and developing technologies:

- Calcium carbide from coal
- Partial oxidation of natural gas
- Electric arc or plasma pyrolysis of coal
- As a byproduct of ethylene steam cracking

The commercially practiced acetylene derivatives that were investigated include:

- Acrylic acid
- Acrylonitrile
- BDO/THF
- Vinyl acetate
- VCM/PVC

Additionally, we looked at prospective acetylene-based products that are technically feasible and might be produced if acetylene can be produced cheaply enough:

- Ethylene (via hydrogenation)
- Benzene (via cyclotrimerization)

2.2 ACETYLENE

Nexant described and reviewed the available technologies for acetylene production and investigated developments that may prove important from both cost and environmental standpoints.

Technology for the production of acetylene via partial oxidation of natural gas is practiced globally and is a mature technology. Acetylene from ethylene crackers is not considered on-purpose production, but accounts for a considerable volume, given the number of crackers worldwide.

Acetylene from coal is dependent principally on the coke to calcium carbide segment of the overall process chain. This technology has seen significant improvements in recent years and is the basis of the overall competitiveness of the process chain and the ability of acetylene to grow as a viable feedstock, especially in comparison to acetylene produced from natural gas.

The use of plasma arc was important historically and is now regaining prominence due to continued improvements from companies like the Solena Group and Westinghouse Plasma Corp.

2.3 ACETYLENE DERIVATIVES

All of the derivatives listed and included in the report have either been produced commercially from acetylene or have been considered, though some of the commercial plants no longer operate. Now, with the possible re-emergence of acetylene cost competitiveness, it is reasonable to assume that some or all of the chemicals will once again be produced from acetylene.

Nexant investigated current and developing technology for the production of these chemicals from acetylene and developed cost of production economics for world-scale plants, with capacities that could compete commercially with conventional technologies and feedstocks.

2.4 TECHNOLOGY DEVELOPMENTS

Nexant has investigated, reviewed and assessed the process and cost implications of new acetylene and acetylene derivative developments. This investigation included contacts with licensors and producers and public domain information, such as patents. After assessing the developments, we incorporated them into the current technology in order to estimate the future state of the technology, and how that attainable technology may impact future competitiveness with current acetylene-based technology and competitive conventional technology/feedstocks.

2.5 ECONOMICS

2.5.1 Acetylene

Nexant prepared cost of production economics for each of the acetylene production technologies (including any other technologies discovered during our research) and the acetylene derivatives. The cost of production economics were prepared for a typical U.S. Gulf Coast (USGC) location for 2006 average prices and unit costs. The cost of production analysis format is similar to a typical cost of production worksheet for VCM from acetylene, as shown in Table 2.1.

Table 2.1 Cost of Production: VCM from Acetylene: China

						CAPITAL COST		**MILLION U.S. $**	
Plant Start-up	2004					ISBL		47.0	
Analysis Date		2004				OSBL		32.9	
Location		China				**Total Plant Capital**		**80.0**	
Capacity		815.7	Million LB/Yr			Other Project Costs		20.0	
		370	Thousand Tons(metric)/Yr			**Total Project Investment**		**100.0**	
Operating Rate		100	Percent			Working Capital		19.5	
Throughput		815.7	Million LB/Yr			**Total Capital Investment**		**119.5**	

PRODUCTION COST SUMMARY			**UNITS**	**UNITS PER LB PRODUCT**	**PRICE U.S. $ PER UNIT**	**U.S. $ PER LB**	**ANNUAL COST MM U.S. $**	**U.S. $ PER Tons**
RAW MATERIALS	Acetylene		LB	0.4400	0.3327	0.146	119.42	
	HCl		LB	0.6300	0.0549	0.035	28.22	
	Catalyst & Chemicals		U.S.$		0.0050	0.005	4.08	
	TOTAL RAW MATERIALS					**0.186**	**151.72**	**410.1**
	NET RAW MATERIALS					**0.186**	**151.72**	**410.1**
UTILITIES	Power (Purchased)		kWh	0.05800	0.0556	0.003	2.63	
	Cooling Water		M GALS	0.00000	0.2289	0.000	0.00	
	Steam, 200 psig (Gas)		M LBS	0.00000	5.4915	0.000	0.00	
	Inert Gas		MSCF	0.00007	1.9459	0.000	0.12	
	TOTAL UTILITIES					**0.003**	**2.63**	**7.1**
	NET RAW MATERIALS & UTILITIES					**0.189**	**154.35**	**417.2**
	VARIABLE COST					**0.189**	**154.35**	**417.2**
DIRECT FIXED COSTS	Laborers,	40	People at	1.65	Thousand U.S. $	0.000	0.07	
	Foremen,	8	People at	2.20	Thousand U.S. $	0.000	0.02	
	Supervisors,	2	People at	3.00	Thousand U.S. $	0.000	0.01	
	Maintenance, Material & Labor			4	% of ISBL	0.002	1.88	
	Direct Overhead			100	% Labor & Supervision	0.000	0.09	
	TOTAL DIRECT FIXED COSTS					**0.003**	**2.06**	**5.6**
ALLOCATED FIXED COSTS	General Plant Overhead			50	% Direct Fixed Costs	0.001	0.99	
	Insurance, Property Tax			0.75	% Total Plant Capital	0.001	0.60	
	Environmental			0.45	% Total Plant Capital	0.000	0.36	
	TOTAL ALLOCATED FIXED COSTS					**0.002**	**1.95**	**5.3**
TOTAL FIXED COSTS						**0.005**	**4.01**	**10.8**
TOTAL CASH COST						**0.194**	**158.36**	**428.0**
Depreciation @		10.0	% for ISBL and OPC	5.0	% for OSBL	0.010	8.35	22.6
COST OF PRODUCTION						**0.204**	**166.71**	**450.6**
RETURN ON INVESTMENT (ROI-Total Plant Capital)				10.0	Percent	0.010	8.00	21.6
COST OF PRODUCTION + ROI						**0.214**	**174.70**	**472.2**

Cost of production economics were performed for the production of acetylene via the process routes shown in Table 2.2.

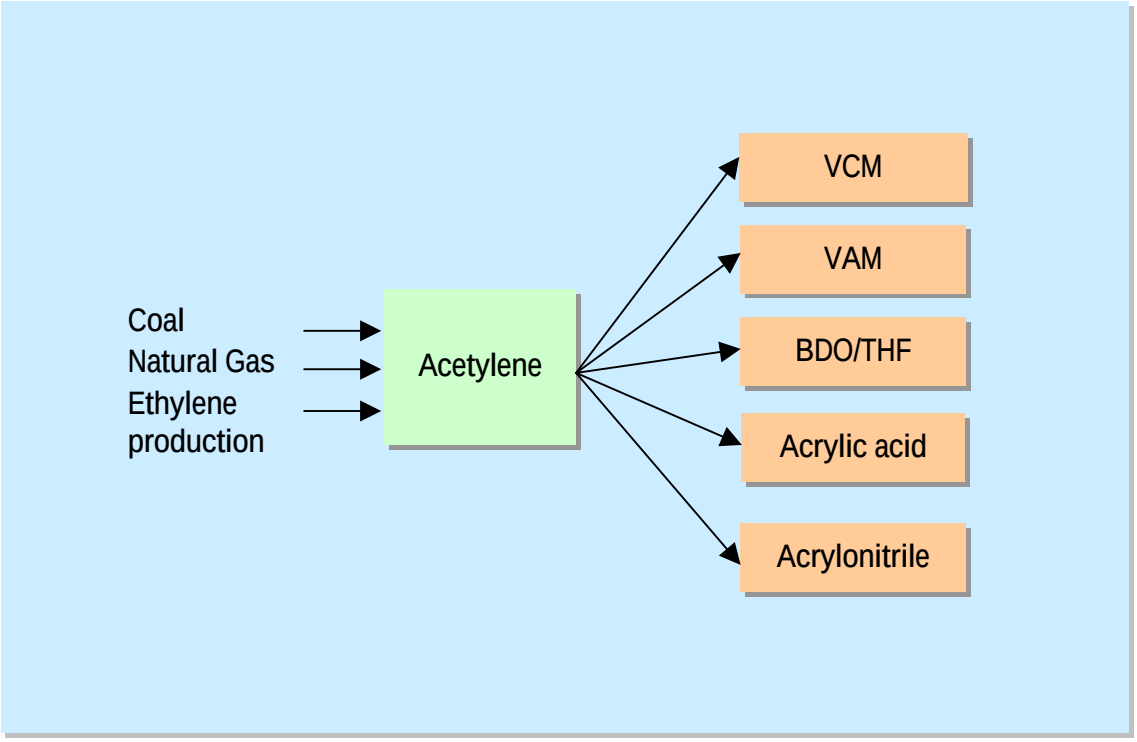
Table 2.2 Acetylene Cost of Production Routes

Calcium carbide from coal
Partial oxidation of natural gas
Pyrolysis of coal
Ethylene byproduct

2.5.2 Commercially Demonstrated Acetylene Derivatives

Nexant developed cost of production economics for those acetylene derivatives that are known to be currently, or formerly have been, produced from acetylene. These include the commercially important chemicals, as shown in Figure 2.1.

Figure 2.1 Acetylene Cost of Production Routes



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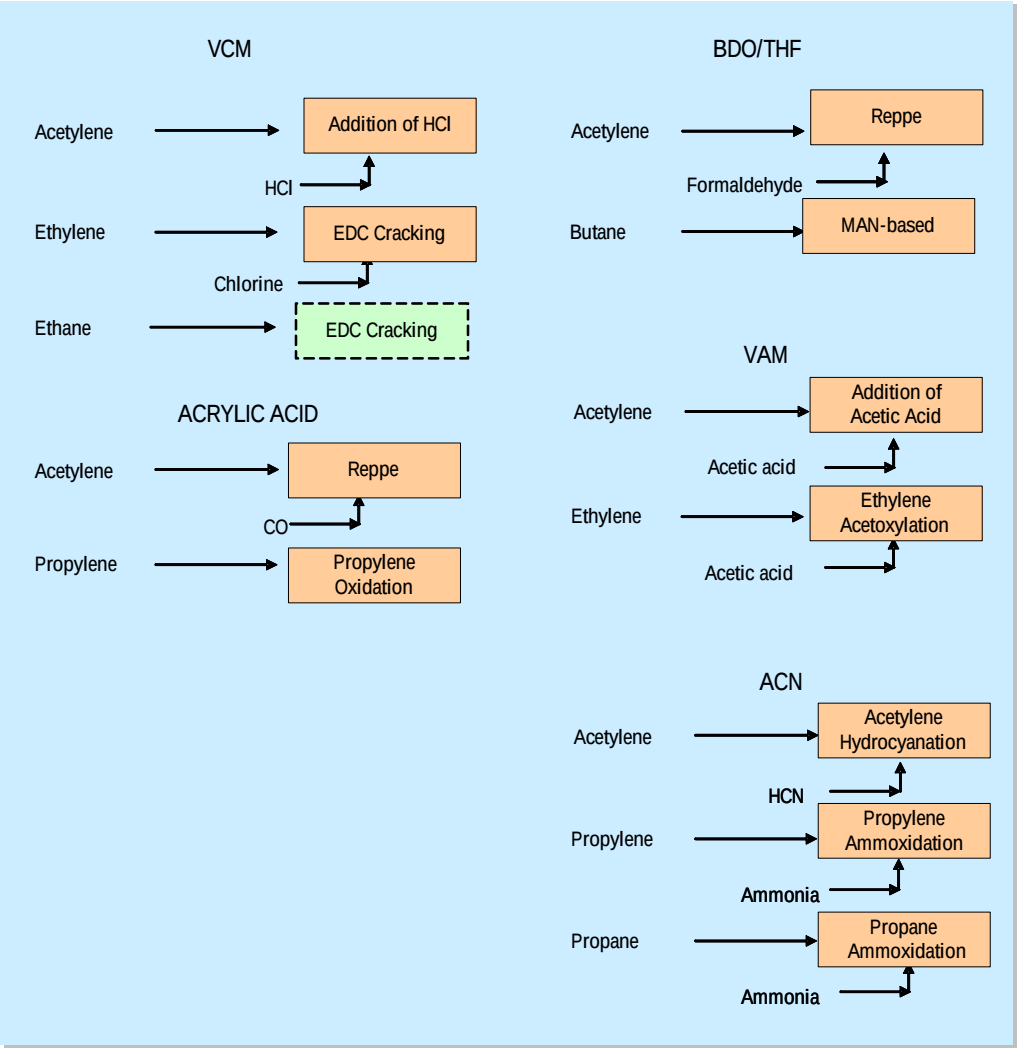
For these acetylene derivatives, we developed cost of production estimates from acetylene for the chemicals listed in Table 2.3 and Figure 2.2 (with major raw materials), as well as for their commercially important conventional routes and feedstocks and other alternate or emerging routes that may prove to be a competitive threat.

Table 2.3 Commercially Practiced Acetylene Derivatives

Petrochemicals	Acetylene-based Process Route	Conventional Feedstock	Conventional Process	Alternate Route	Emerging Route
VCM/PVC	Addition of HCl	Ethylene	EDC cracking		Ethane oxidation
BDO/THF	Reppe	Natural gas	MAN-based		
Vinyl acetate	Addition of acetic acid	Ethylene	Ethylene/acetoxylation		
Acrylic acid	Reppe	Propylene	Propylene oxidation		
Acrylonitrile	Acetylene hydrocyanation	Propylene	Propylene amoxidation		Propane amoxidation

Figure 2.2 Commercially Practiced Acetylene Derivatives Process Routes



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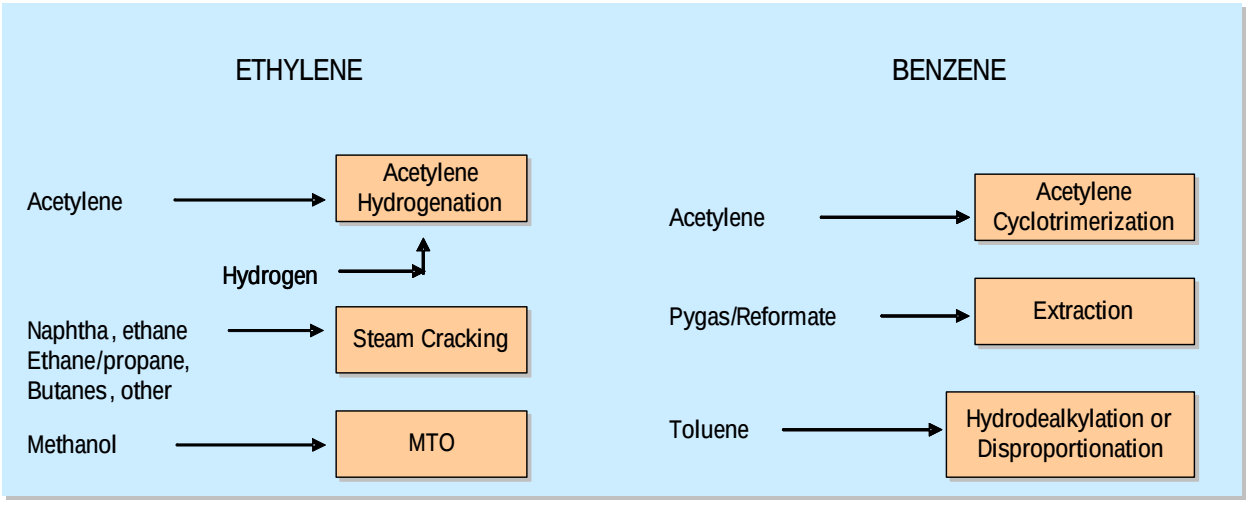
2.5.3 Prospective Technically Feasible Acetylene Derivatives

For ethylene and benzene, Nexant developed process schemes and estimated costs of production, including capital costs, yields, utility consumptions, etc., for the theoretical commercial-scale acetylene hydrogenation and acetylene cyclotrimerization routes, respectively. Acetylene hydrogenation is already practiced in small scale as part of ethylene cracking technology, but we scaled the technology up to represent a competitively-sized ethylene plant. For benzene via acetylene cyclotrimerization, we estimated a commercial process based on the chemistry and unit operations. As in the case of commercially demonstrated derivatives, we compared the acetylene-based costs of production to major conventional technology, as shown in Table 2.4 and Figure 2.3, and emerging technologies that also potentially represent low cost alternatives to conventional technology, such as the emerging methanol to olefins (MTO) technology that offers the promise of producing ethylene and propylene from low-cost stranded, remote gas reserves. MTO technology is already envisioned as a competitive source of olefins, but may be challenged by acetylene-sourced ethylene from the same natural gas or from low cost coal regions.

Table 2.4 Prospective Acetylene Derivatives

Petrochemicals	Acetylene-based Process Route	Conventional Feedstock	Conventional Process	Alternate Route	Emerging Route
Ethylene	Acetylene hydrogenation	Naphtha, ethane, E/P	Steam cracking		Methanol to olefins
Benzene	Acetylene cyclotrimerization	Pygas to reformate	Extraction	TDP or THDA	

Figure 2.3 Prospective Acetylene Derivatives Process Routes and Commercial Comparison



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2.5.4 Economics

All economic summaries represented world scale capacities for each derivative chemical. The competitive economics for each chemical derivative was performed on a consistent basis; that is, for the identical capacity, location and unit costs, to ensure a meaningful comparison on cost of production terms.

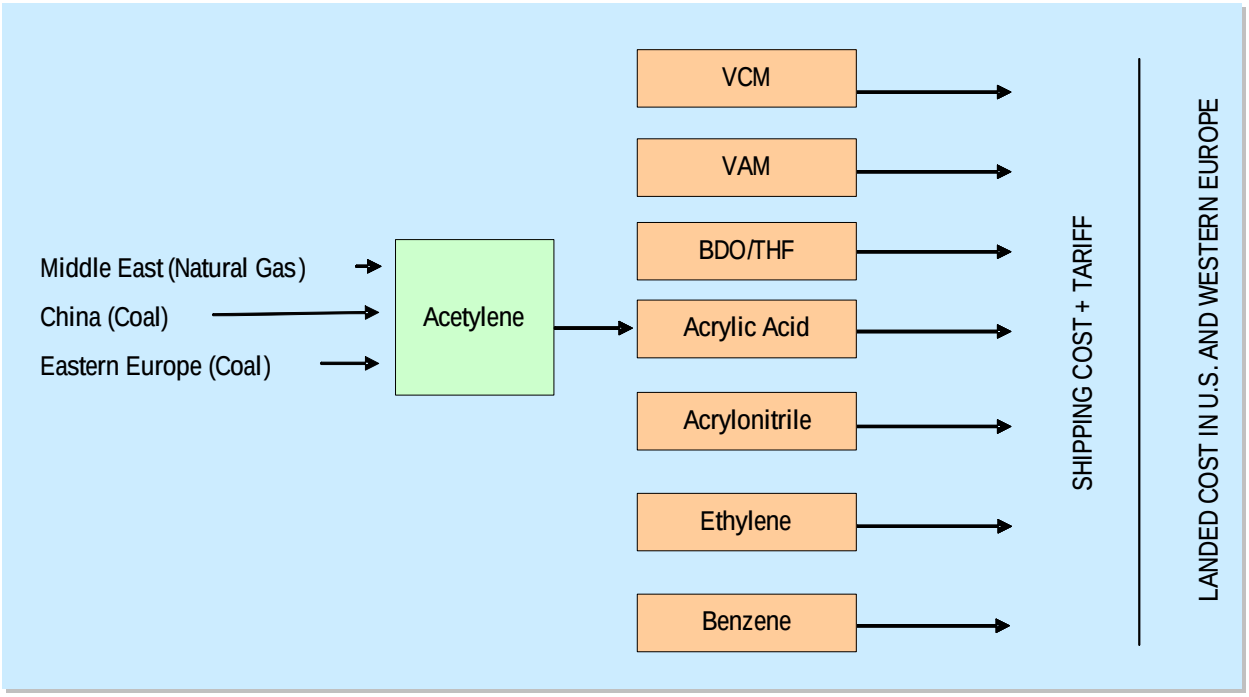
The acetylene cost of production economics were developed for identical capacities, location and unit costs and were sized to produce enough acetylene for the world-scale derivative plants. Limitations in train size were included (such as maximum size and number of furnaces for the calcium carbide production, rather than a simple "scale-up" as if a single-train plant), and multiple trains were incorporated where necessary, with respective capital cost and fixed cost effects and implications taken into account.

2.6 REGIONAL ECONOMICS

Nexant developed cost of production economics for the various comparative acetylene processes and acetylene chemical derivatives processes listed on a regional basis, taking into account typical regional conditions, including:

- Cost of production estimates for forecast 2006, 2010 and 2015 prices and unit costs were developed for each of the processes and feedstocks for comparison of both acetylene production (via the various routes and feedstocks) and the derivative chemicals (from acetylene and from the conventional and emerging processes and feedstocks).
- Because coal-based acetylene is such an intriguing growth route, costs were developed for the regions/countries with major accessible coal reserves, such as the United States, China, and Eastern Europe. Regions with low-cost natural gas, such as the Middle East, were also included, since the natural gas to acetylene route might have advantageous economics there.
- In order to gauge the export potential for low-cost acetylene producing regions (i.e. those with low-cost coal and natural gas), we estimated the costs to produce the more commonly traded derivatives in those regions and export (including shipping and duties) to the United States and Western Europe, where they were compared to market prices or domestic costs of production. Figure 2.4 summarizes the export economics performed.

Figure 2.4 Export Economics Cases



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The economic comparisons are used to help develop regional production and competitive dynamics, which were illustrated by comparing the delivered cost of the product to a typical import location. Thus, VCM competitiveness was shown by developing costs for a VCM plant or VCM/PVC complex as exported to the USGC and Western Europe after being produced in China and Eastern Europe (from coal-based acetylene). This was compared to the VCM/PVC market price or cost of production in those regions.

Because the possibility of producing ethylene from low-cost acetylene competitively shows potential, we compared this production from stranded or remote gas reserves, such as the Middle East. In addition, these costs were compared to ethylene produced from acetylene based on coal from low-cost coal countries that may also compete in the same export markets.

Nexant developed a price forecast through 2015 for the countries and regions involved in the production cost estimates. These estimates included all major raw materials, byproducts and utility and wage unit costs. ISBL (inside battery limits) and OSBL (outside battery limits) capital costs will be estimated for each process on a USGC basis and will be adjusted for the particular countries and locations using our technology database of construction cost location factors. Location factors for labor force size and costs (social charges) and general plant overhead were also applied.

Sensitivities were performed for important design and cost bases, and estimates were made as to potential improvements and their implications.

2.7 COMMERCIAL EVALUATION

Nexant developed forecasts of the major product groups included in the technoeconomic evaluations. The forecasts included demand, production and trade, globally and by region, to 2020.

3.1 CHEMICALS FROM ACETYLENE: BACK TO THE FUTURE?

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

Nexant used its own proprietary as well as commercial state-of-the-art software tools to develop the technology and economic estimates. We employed well established, state-of-the-art chemical process industry engineering estimating tools and principles as used by major engineering contractors. To the degree allowed under copyright and licensed user restrictions, the detailed software generated output will be made available upon request.

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

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

The study was completed in June 2007.

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

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4. Client further agrees that it will use reasonable efforts to keep the information in the reports for its sole use; however, this restriction shall not apply to information which is or becomes generally available to the public in a printed publication, which is already in the possession of Client, or which is received by Client in good faith from a third party without an obligation of confidentiality.

5. Client shall not republish any of the report except within its own organization or that of its 51 percent or greater owned affiliates. Client further agrees to refrain from any general publication of the reports, either directly or through its affiliates, so as to constitute passage of title into the public domain or otherwise jeopardize common law or statutory copyright in said report.

6. Client will be billed by and shall pay Nexant a total of US$17,500 (seventeen thousand five hundred U.S. dollars). Amounts are due upon receipt of invoice and payable within thirty (30) days. Late payments shall accrue interest at the rate of 1.5 percent per month. Fees quoted do not include any applicable sales tax, or use or value added tax, all of which are for the account of Client.

7. Additional copies of the report are available at US$500 each. The complete report will also be available electronically on CD-ROM at a cost of US$1,000.

8. The obligations of paragraphs 3 and 4 shall terminate five (5) years from receipt of reports.

9. Unless specified otherwise, there are no warranties of any kind for reports and consulting services provided under this Agreement. Nexant’s total liability under this Agreement is limited to the total amount paid to Nexant for the reports.

10. This Agreement will be governed by the laws of the State of New York.

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7.1 GENERAL

7.1.1 Nexant

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

Nexant's global headquarters are in San Francisco. The company provides a range of services to the energy industries, as detailed in our literature and on our website at www.nexant.com.

7.1.2 Nexant Petroleum and Chemicals Division

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

Our P&C Division services span the entire industry value chain, from oil and gas production through the downstream sub-sector to chemicals, including specialty chemicals. These services complement Nexant's other divisions, which provide a comprehensive range of consulting services and software to the electric power and advanced energy sectors.

Nexant's P&C Division offers its clients **Insight and Understanding** – Our sharp focus on the petroleum and chemical industry gives us unrivalled insight into the current issues and opportunities; the shifting landscape and changing fortunes that affect the sector. We understand our clients businesses - the challenges they face and the competitive pressures which shape their thinking.

This can only be achieved through an unrivalled combination of:

- **Industry knowledge** - we consult on the petroleum and chemical industry; our consultants are all experts in the industry who work fulltime on the challenges facing the industry.
- **In-house data** - we have an unrivalled database on the industry and its markets, and employ teams of researchers to continually update this resource. Our *ChemSystems Online* product, which can be accessed by subscribers, contains the core of this knowledge base covering the commodity chemicals and polymers.

- **Proven and tested methodologies** - we have developed a range of methodologies to cover different types of assignments, such as feasibility studies, project finance support, privatizations, due diligence studies for acquisitions and financings, market and technology review, and selection studies. All of these have been tailored and continuously improved to suit the needs of the industry.
- **Technical competence** - we constantly track the technical improvements in the industry and frequently review new process improvements for clients. Our Process Evaluation/Research Planning Program (PERP) product encapsulates some of this work and is available to subscribers.
- **Global** - our permanent offices in London, New York (White Plains), Houston, Tokyo, and Bangkok provide comprehensive coverage. In addition, we have long-term relationships with representatives or registered branch offices in most major locations, including Beijing, Singapore, Seoul, Moscow, and Buenos Aires. Nexant professionals have extensive experience in emerging markets such as the former Soviet Union and China, and our team of industry experts can work fluently in over ten languages.
- **Strategic consulting** - we have been on the leading edge of many of the strategic initiatives in the industry, including consolidations, restructuring, and privatizations. We pride ourselves on our thought leadership in strategy consulting in the sector.
- **Breadth** across all relevant sectors. Our team can provide clients with a complete and holistic view of the sector and its place in the overall economy covering the entire value chain.

Nexant P&C has unrivalled experience:

- Each year Nexant advises on tens of billions of dollars of petroleum and chemicals projects in most of the major global supply and demand centers, covering the full hydrocarbon production, processing and transportation supply chain.
- Our team routinely works for almost every major multinational corporation in the petroleum and chemical business and for many national companies, governments, and international organizations. Nexant's view is often quoted by major corporations as an authoritative view on the industry.

We are recognized for our quality and industry thought leadership:

- Nexant is often quoted in the petroleum and chemical press on its views on markets and developments.
- Our team members are called on to give expert papers at major conferences.
- Our team of experienced vice presidents is responsible for the quality of our work in their individual areas of expertise. They are expected to provide inputs to and supervise every assignment we undertake.
- Our UK-based group has twice been honored with the "Consultant of the Year" by The Times newspaper/BCCB. The first time in 2000 for work on the cost implications of the

European Commission's program of automotive fuel specification improvements, and again in 2002 for the innovative *ChemSystems Online* product.

We have extensive resources to fulfill any assignment in the industry:

- Nexant P&C employs over one hundred staff, making us the largest specialist consultant in the sector. We are the only industry specialist consultant to offer a fully comprehensive in-house service from well-to-wire and to downstream chemical.
- All staff are experienced in the industry and have typically worked previously for a multi-national industry company or a major contractor/technology company. More than half of our staff have worked for Nexant and the predecessor organizations for more than ten years.
- Staff qualifications include chemists and engineers as well as economists and legal specialists. A very high proportion of staff has advanced degrees - PhD or MBA.
- We can staff projects anywhere in the world from our global network of offices.
- Our data resources are the best in the industry and are continually updated.

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.

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)
- *ChemSystems Online* (CSOL)/Petroleum and Petrochemical Economics (PPE) Program – United States, Western Europe and Asia

The PERP service covers technology, commercial trends, and economics applicable to the chemical industry. The program has more than 50 subscribers, including most of the major international chemical companies. Many of the processes to be analyzed in this multiclient have been assessed in the PERP program.

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

Over the past five years, the 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.

The new 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:

- Plant capacity
- Production
- Consumption
- Supply/demand and trade
- Profitability analysis
- Forecast
- Price forecast
- Techno-economic analysis

A subscription to *ChemSystems Online* includes both written reports (the PPE program) on the petroleum and petrochemical industry and internet access to all data analysis and forecasts. Your subscription may be tailored to meet your specific company requirements and the fees reflect the value brought to your business. Insightful analysis and a reliable forecasting methodology provide the means to significantly improve your business performance though better investment decisions and improved competitive position.

7.2 SUMMARY OF PROJECTS RELATED TO COAL

- **SYNTHETIC FUEL CAPITAL AND PRODUCTION COSTS** -- Nexant performed this study for the U.S. Department of Energy (DOE) as input to their assessment of the costs and benefits of flexible and alternative fuel use in the U.S. transportation sector. Nexant reviewed state-of-the-art coal liquefication technology and developed production cost estimates for producing synthetic crude and then upgrading the syncrude to a gasoline product.
- **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, Byproduct, 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 were included in the study, which also reviewed the chemical implications of synthetic fuels programs in the United States and elsewhere. A section on utilization of U.S. tar sands resources is included.
- **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 byproducts 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/BYPRODUCTS** -- 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 byproducts. 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 and 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.

MULTICLIENT STUDIES

- **COAL TO CHEMICALS: IS IT COAL'S TIME AGAIN?** -- In this multiclient report, Nexant examined the costs of production for the production of chemicals using both coal and conventional feedstocks in China and the United States, including technologies for coal gasification and chemical derivatives and chemicals from acetylene technologies: acetylene, BDO, formaldehyde (REPPE concept), VCM, vinyl acetate, acrylic acid via REPPE process.
- **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.

7.3 SELECTED PROJECT EXPERIENCE IN NATURAL GAS UTILIZATION

Projects described below involved the full range of services including strategic assessments of energy options, market analysis and forecasts, process selection, cost estimating, financial analysis, preparation of bid documents, contractor selection and project management through to plant operation. These summaries also include a number of projects, principally in the petrochemical area, based on natural gas feedstocks.

- **OPPORTUNITY ANALYSIS** -- An Argentine petrochemical producer came to Nexant for an independent evaluation of the future supply and demand of natural gas and petroleum-based feedstocks for the Argentine industry. Nexant profiled the following: key petroleum and natural gas producing sites and proven reserves - ownership, annual production, reserve level, planned expansions; existing and planned pipelines and distribution systems; locations, capacities, production, planned expansion of the refineries; quality characteristics of hydrocarbon resources; historical and forecast (to 2005) for supply and demand of crude oil and condensate, natural gas, ethane, LPG, naphtha; sites that would support world scale olefin or aromatics operations. Using this information, Nexant identified potential investment opportunities for the client in Argentina.
- **PRICING ANALYSIS** -- Nexant was engaged by a Scandinavian company to study long-term (to 2017) natural gas pricing in Bolivia. The project addressed the following: overview of economic and regulatory developments; profiles of energy reserves; infrastructure development; energy use trends; pricing determinants, such as gas supply/demand; and alternative use value.
- **PREFEASIBILITY ANALYSIS** -- For a joint venture between an Indonesian and Malaysian producer who intended to develop a petrochemical industry based on indigenous natural gas in Borneo, an analysis of the economic basis for a MTBE facility supplied by natural gas/*n*-butane feedstocks was required. Nexant evaluated the following: suitability of the feedstock; the Asian markets for MTBE and methanol; plant size required as compared to world-scale, and capital costs.
- **EXPERT WITNESS** -- Nexant's role in a litigation consisted of evaluating one of the litigant's proposed Gas Conversion Facility Project plan and testifying as an expert witness on the viability of the project.
- **GAS DEVELOPMENT STRATEGY** -- A Chilean energy agency retained Nexant to advise on the development of a natural-gas based fuel strategy in Santiago, following an earlier Nexant study that determined that LNG was the optimal substitute for diesel fuel in large vehicles. Pursuant to this conclusion, Nexant was engaged to address the following: incremental cost of CNG vs. LNG; LNG production, storage, transportation system costs; availability of OEM LNG vehicles; availability of LNG tanks; cost of converting CNG to LNG.

- **NGL UTILIZATION** -- For a developing Russian project partnered by a U.S. company, utilizing Siberian gas in more developed regions, Nexant assessed and made recommendations on: products to be made, facilities required and the economics as related to ethane.
- **DUE DILIGENCE** -- For a Peruvian bank planning to participate in financing a proposed refinery expansion, Nexant provided an independent review of the technical and commercial feasibility of the investment that included: domestic and international markets; feedstock and product pricing, operating costs and cashflows, technical review, and risks and downside.
- **NATURAL GAS UTILIZATION** -- An Australian client interested in developing natural gas fields that contained undesirable amounts of inert gases for industrial gas customers engaged Nexant to assess the suitability of these resources as chemical feedstocks or as fuel in a variety of applications: direct reduction of iron; steel making; methanol; ammonia/urea; chloralkali; ethane-based petrochemicals. In each case, gas consumption, specifications, cost of gas treatment, if any, problems or benefits from impurities and the cost benefit of several levels of treatment were determined.
- **NATURAL GAS OPPORTUNITIES** -- Nexant worked with the national oil company of Argentina and the government on the implementation of a program to make optimum use of indigenous natural gas resources. The natural gas use included alternative transportation fuels, such as compressed natural gas (CNG), methanol and MTBE, displacing imported crude oil and allowing export gasoline and benefit to the national balance of payments. Nexant's role was: to review international experience for natural gas processing; to apply experience to requirements for transportation fuels; to recommend natural gas processing technologies; and to evaluate oil refinery modernization/rationalization plans.
- **OPPORTUNITY ANALYSIS** -- A major U.S. chemical producer interested in developing and producing hydrocarbons in Asia engaged Nexant to determine the market opportunities for available methane in selected regions in China for petrochemical or related products. We provided the following: an overview of the Chinese energy market and the role of natural gas in energy, industrial and chemical applications; infrastructure overview in the target regions/locations; focused assessment of natural gas opportunities for chemicals and for energy/industrial applications in the selected regions.
- **GAS CHEMICAL SCREENING** -- For a major U.S. chemical company seeking to identify and evaluate viable chemical outlets that could consume significant qualities of remote gas resources in world-scale facilities, Nexant screened a broad group of major chemicals that were first or second derivatives of methane. For the chemical selected in the screen, market-related information, including global supply/demand, demand growth projections, technology licensors, production economics, business overview and technology improvements that can create economic advantage, was provided.
- **MARKET ANALYSIS** -- A U.S. company planning the construction of a natural gas to liquids (GTL) plant to produce a feedstock for use in higher value product mix of synthetic hydrocarbon products commissioned Nexant to thoroughly evaluate the

marketplace for the planned products -- naphtha, *n*-paraffins, tail gas, synthetic drilling fluids and lubricant stock. Nexant provided: historical, current and projected pricing for the products; analysis of the current and projected supply and demand for each of the products; analysis of the cost structure of competing products; potential pricing indices to be used for contracting; and suggestions for improvements in the product slate/mix and downstream investments that would access higher value markets.

- **TECHNOLOGY ASSESSMENT** -- A U.S. client interested in identifying applications for a membrane-based oxygen enrichment technology contacted Nexant for an evaluation of a technology to convert natural gas to liquid fuel. Specifically, the study identified gas conversion technologies most amenable to use of oxygen enrichment, determined the volume of oxygen required, and the current status of the conversion technologies, complete with production economics.
- **PRODUCTION ECONOMICS** -- Nexant developed the cost of producing dimethyl ether (DME) via a recently announced process in large-scale natural gas plants and delivering it as a substitute for conventional diesel fuel. The client was also interested in comparing DME production costs with other alternative processes for converting remote natural gas to a fuel product.
- **TECHNOECONOMIC EVALUATION** -- Nexant was retained by a Japanese energy agency to evaluate the status and trends of natural gas conversion to liquid fuels technologies. Processes already commercial (Sasol, Mobil, Shell), ready for commercialization (Exxon, Haldor Topsoe), as well as under development (Syntroleum, Statoil), were assessed and comparisons made with competitive processes. For each of the processes, detailed descriptions of the investment required, the feedstocks and chemistry of the processes, and the costs of production were provided.
- **MARKET POTENTIAL** -- The natural gas division of an international petroleum company retained Nexant to determine the market potential for natural gas-based chemicals including: ammonia, urea, methanol, acetic acid and for novel conversion technologies. Nexant provided the global market size, growth factors, cost of production (ammonia, methanol, acetic acid) and an overview of primary technology licensors or contractors who are candidates as partners.
- **NATURAL GAS UTILIZATION** -- A joint venture of Nexant and Davy McKee for the Petroleum Authority of Thailand identified all possible uses for natural gas and associated liquids in Thailand, and an investment analysis for each of the recommended uses. The economic benefits for each recommended use were ranked into a priority development order. A priority development program was developed. Nexant provided all market evaluations for fuel, fertilizers and petrochemicals, including analyses of global trade in energy products, and established the price-setting marketing mechanisms for all energy and petrochemical commodities that would have to be achieved by the natural gas liquids and petrochemical producers of Thailand. Nexant also established estimates of competitive supplier economics based on their feedstock cost and characteristics, infrastructure costs, plant capacities, and investments and transportation elements. Values of products were used to optimize the Thai natural resource respecting

domestic fuels, natural gas liquids (NGL) for petrochemical exports and fuel exports. Nexant provided training for personnel in the procedure for project development and evaluation and transferred software to PTT for future use.

- **ASIAN PRICING** -- A U.S. engineering/construction services company required information related to the outlook for Asian high sulfur fuel oil (HSFO) for used in negotiations on gas sale agreements. Nexant explained recent crude oil pricing forecast scenarios and the basis for Asian HSFO forecasts, consistent with the crude outlooks. Price forecasts through 2020 were provided.
- **CARIBBEAN FEASIBILITY STUDY** -- Nexant assisted a U.S. gas producer to determine the viability of an ethane-based cracker in the Caribbean. For this project, a market outlook for polyethylenes (LDPE, HDPE, LLDPE) and EO/EG was provided; target markets determined; prices forecast; cost of production and return on investment estimated.
- **CHEMICAL TRADE IN LATIN AMERICA** -- The gas and basic petrochemicals division of the national oil company of Mexico commissioned Nexant to assist it in framing a free trade agreement (FTA) between Mexico, Venezuela and Colombia. Nexant's primary role was to provide support and advice to the leader of the Mexican team in negotiating aspects of the FTA affecting the energy and chemical industries in the three countries. Nexant comprehensively reviewed the petroleum, natural gas, gas processing, oil refining and chemical industries in Venezuela. The international competitiveness of these industries in Mexico and Venezuela was compared, and structural changes in these sectors were evaluated along with potential changes in bilateral trade patterns resulting from a free-trade environment. Nexant also addressed the mutual benefits and disadvantages for each country associated with the products of these industries in an effort to anticipate issues that would arise in the discussions.
- **NATURAL GAS DEMAND** -- This study, funded by the World Bank, provided a detailed projection of demand for natural gas in Pakistan and compared this with projected supply from production fields. The project included identification of potential problems and recommended corrective action.
- **RESOURCES UTILIZATION STRATEGY** -- Nexant was retained by the Liquid Fuels Trust Board of New Zealand to perform a strategic assessment of indigenous energy resource uses. The focus of the analysis was the use of LPG and ethane to produce fuel and chemical products. Nexant identified the potential products that could be economically produced in New Zealand utilizing feedstocks derived from the Maui and Kapuni gas fields, in order to develop alternative strategies for the optimum utilization of these resources. In addition, costs to extract NGLs were determined as a necessary first step in evaluating the viability of producing derivatives for both fuel and petrochemical use. Pricing policies were developed for the LPG and ethane based on the alternative uses available. The analysis included a characterization of current and future fuel requirements in the country and an assessment of alternative technologies that could be used to meet the future fuel requirements.

- **MASTER PLAN DEVELOPMENT** -- Nexant and Davy McKee were retained to develop a master plan for optimizing the use of natural gas in Malaysia. The project consisted of the following: providing current and future energy demand pattern within Malaysia; developing natural gas utilization program with emphasis on the maximum use of natural gas and NGLs as a potential replacement for crude oil derived products (diesel and gasoline); evaluating the Malaysian, regional and global petrochemical markets to determine which natural gas and NGL-based petrochemical products which should be produced in Malaysia; recommending alternative technology; formulating an investment program, by region in Malaysia; training staff on methodology for project conceptualization, evaluation and implementation.
- **NATURAL GAS IN INDUSTRY** -- Nexant was retained by The World Bank to analyze the value of natural gas in alternative industrial sector applications and to provide guidance for ranking the different potential uses for gas to optimize utilization of limited gas resources. The analysis considered the following potential applications for natural gas and gas liquids: ammonia, urea, ammonium nitrate or other nitrogenous fertilizers; methanol and derivatives; ethylene and derivatives; propylene and derivatives; liquefied petroleum gas; energy-intensive industries such as cement, or metallurgical industries. For each natural gas/gas liquids application, the value of natural gas in that application was developed using the following criteria: global and regional product market overview; product price forecast; production and investment costs; developed site with infrastructure and low construction costs; developed site with infrastructure and high construction costs; developing site with some infrastructure provided developing site in a remote location with no infrastructure; effects of plant size and cost; degree of product export; distance to market. Results were presented in a form that allowed the bank to develop a preliminary specific analysis for a particular project location.
- **NATURAL GAS POLICY** -- For the American Gas Association Nexant examined strategic questions regarding U.S. policy on manufactured gas versus naphtha for fuel uses. The fuel uses of naphtha examined in the study include its use as: a feedstock to a substitute natural gas (SNG) plant, No. 2 fuel oil, motor gasoline and jet fuel. The thermal efficiency of naphtha from when it leaves the refinery's crude oil pipe still (or delivered from foreign sources) to when it is finally converted into useful energy was determined.
- **LPG FOR TRANSPORTATION** -- Nexant was commissioned by Yacimientos Petroliferos Fiscales (YPF) to develop an implementation plan to promote the use of LPG as a vehicle fuel in Argentina, where it was prohibited. The study assessed the competitiveness of LPG compared to gasoline, diesel and CNG for various market sectors. The study addressed technical issues related to LPG use, legislation required to regulate LPG use, as well as safety considerations and infrastructure requirements (service stations and transport).
- **ARGENTINE FEEDSTOCK AVAILABILITY** -- Nexant evaluated future feedstock availability to support this country's restructured petrochemical industry. Natural gas pipeline projects (current and future) to Chile and Brazil were reviewed and refined product trading in the area was profiled.

- **NATURAL GASOLINE AND CONDENSATE MARKETS** -- Nexant carried out a market opportunity study on natural gas liquids, identified the likely markets for propane, butane, natural gas and condensate originating from a plant in the province of Neuquen. Nexant studied condensate value and processing options, the refinery processing structure and analyzed marketing logistics and infrastructure. The study identified market opportunities in Argentina, South America and internationally, provided supply/demand balances by South American country, and estimated netback prices.
- **INDUSTRIAL PLANNING** -- SABIC enlisted Nexant to work them on developing fertilizer and petrochemical industries based on natural gas resources. Nexant provided senior advisers resident in SABIC's offices in Riyadh to assist on all matters related to the development of Saudi Arabian industry.
- **GAS STRATEGY FOR MEXICO** – This assignment entailed assisting the newly formed gas unit of PEMEX in the formulation and implementation of an overall corporate strategy, structuring all key aspects of operating a gas company, and establishing a viable Mexican gas industry with emphasis on developing marketing and pricing strategies.
- **NATURAL GAS PRICING** -- A major Western European gas authority engaged Nexant to advise on a proposed change in gas pricing to the fertilizer industry. Key issues addressed were the form and detail of the new pricing formula to be adopted, the control of the proposed rebate mechanism and the implications for competition on both a regional and a global level.
- **NATURAL GAS UTILIZATION IN PERU** -- Nexant was a member of a World Bank Mission evaluating natural gas utilization opportunities in Peru. The study covered the following: fuel substitution markets; power generation markets; alternate feedstock uses for ammonia/urea and methanol (evaluation of investment and operating costs, market potential and netbacks); residential/commercial demand; ranking of alternative uses; specific local/regional demand sectors under alternate strategies; effects of alternate strategies in the refinery sector.
- **GLOBAL GAS UTILIZATION** -- Nexant has participated in several gas utilization and related energy assessment missions arranged by the World Bank for the Ivory Coast, a net importer of petroleum to supply its energy needs that has substantial offshore natural gas reserves that could be of benefit to the Ivory Coast economy if developed. Nexant evaluated the potential for the development of the natural gas markets and provided a plan to implement this development. The assessment evaluated fuel substitution options, including the use of natural gas and natural gas liquids for motor transport. Also included was an evaluation of the infrastructure changes required to yield a substantial use of natural gas in these applications. A program for achieving objectives was developed and presented to the government. As part of a World Bank mission to Tanzania, Nexant's evaluation of natural gas utilization opportunities included: review and estimate sectoral energy demand (national and by key regions); estimation of potential demand for natural gas by key sectors and regions; estimation of magnitude of investment and potential economics/economic benefits for increased use of natural gas; reported analysis,

conclusions and recommendations of the Mission (closely coordinated with World Bank personnel).

- **GAS TREATING DUE DILIGENCE** -- For a Canadian financial institution requiring an operational and technical due diligence review of a natural gas treating facility that removed carbon dioxide from the gas, Nexant reviewed: the ability of the facility to handle the contracted amount for the life of the contract; the ability to accommodate increasing levels of CO_2 in the raw gas stream; tradeoff between treating gas with higher CO_2 and processing capacity; level and type of routine maintenance necessary; redundancy factors and components to handle accidental down time; as well as the ability to operate if supplied electric power is cut off; and the likelihood of a new technologically superior process.
- **LNG, FERTILIZER AND PETROCHEMICAL DEVELOPMENTS** -- Technical support on a variety of energy, chemical, petrochemical and fertilizer process plants, all derived from natural gas feedstocks: ethane, ethylene, LDPE, VCM, PVC, chlorine, caustic soda, LNG, ammonia, nitric acid, ammonium nitrate, urea, STPP.
- **PETROCHEMICAL STUDIES** -- Nexant was retained by an Egyptian governmental agency for independent feasibility studies of the potential for establishing olefins and aromatics industries within the Arab States. This strategic assessment assisted decision makers in the respective states to implement oil and gas utilization programs, thereby, giving maximum overall long-term benefits to the Arab economies.
- **NATURAL GAS-BASED PETROCHEMICALS** -- Nexant was retained by the Nigerian Federal Ministry of Industries as Technical Adviser for the planning of the country's petrochemical developments. This involved a major study of the domestic and West African markets and their growth potential, the development of investment options and their preliminary appraisal, the identification of potential joint venture partners and the preparation of a detailed implementation plan.
- **NATURAL GAS MARKET AND IMPORT STUDY** -- For a North European gas distributor, Nexant determined affordable prices for new natural gas imports into Europe to the year 2000. Nexant based its analysis on cost of end uses in the markets where natural gas competes with various grades of refined petroleum products. Estimates of transmission and distribution costs were then subtracted to arrive at values at various European borders. Future gas market projections were made on the basis of changes resulting from various energy programs of European countries and changes in the oil product pricing structure.
- **NATURAL GAS COMPETITIVENESS** -- For a West European gas distributor, Nexant examined thirteen broad industrial markets in Belgium, France, Germany, The Netherlands and the United Kingdom and categorized the energy use for these industries into premium and non-premium fuels. The analysis included residual fuel oils, gas oils, kerosenes, liquefied petroleum gases (LPG) as petroleum derivatives, and their production and distribution economics in the respective countries. The end uses included process uses of premium fuel, process non-premium uses, boiler fuel, space heating and other domestic industrial uses. The cost trade-offs included oil storage, oil heating,

chimney heights, sulfur dioxide control, equipment design, labor, maintenance and equipment capital costs for major applications in each industry. The results of these analyses led to a listing indicating the price premium that can be commanded by natural gas compared with the competing petroleum-derived fuel for each industrial application.

- **NATURAL GAS UTILIZATION/PRICING** -- A Malaysian governmental agency retained Nexant to assist in the evaluation of the feasibility of methanol, ammonia and ammonia/urea projects in Malaysia and development of a strategy for the marketing of the products in the logical export markets. In addition, Nexant defined natural gas realization values for the alternative projects, given acceptable project profitability levels.
- **NATURAL GAS TRANSMISSION** -- Nexant was commissioned by the Government of Bangladesh, through The World Bank, to independently evaluate the Chittagong area gas demand potential to determine the diameter of transmission pipelines and whether construction should be immediate or delayed. Overall viability of gas development and the pipeline project was evaluated and recommendations were presented on design criteria and project implementation.
- **NATURAL GAS UTILIZATION AND EXPORT** -- Nexant was commissioned by a Trinidad/Tobago agency to compare the economics of LNG production versus methanol production for shipping to various world markets. Product pricing in consuming regions, shipping costs, and production economics were developed, and LNG and methanol were compared on a netback gas valuation basis.
- **NATURAL GAS LIQUIDS VALUATION** -- Nexant was commissioned to study the value of natural gas liquids (NGL) produced from the North Sea. The evaluation involved considering the use of NGL as olefin plant feedstocks in the U.K. versus export to Europe or the U.S. for use as feedstock or fuel. Cost of production estimates were developed for NGL crackers and for major derivatives units.

MULTICLIENT STUDIES

- **STRANDED GAS UTILIZATION: STEPS TO COMMERCIALIZATION --** This multiclient report focuses on the approaching commercialization of emerging technologies that convert remote gas to higher value fuels and chemicals
- **STRANDED GAS UTILIZATION: METHANE REFINERIES OF THE FUTURE --** This report contains an extensive analysis of the technologies and markets that will utilize remotely located natural gas resources in the coming years
- **PETROCHEMICALS FROM REFINERIES** -- This in-depth business assessment evaluated opportunities to produce high value petrochemicals from lower value refinery streams. The analysis examined the operational and capital costs benefits of integrated operations versus standalone petrochemical facility construction. The study also evaluated the global market outlook for over twenty petrochemical products. The profitability of producing these products from pro forma refineries located in the world's three major refining centers (USGC, Singapore, Rotterdam) was evaluated.

- **THE LATIN AMERICAN ENERGY, REFINING AND PETROCHEMICAL INDUSTRIES IN TRANSITION** -- A geographically-focused business assessment that evaluated the key issues facing the energy and refining industries in all major Latin American countries. Industry competitiveness was assessed and energy and major petroleum product supply/demand trends analyzed for each country and the region.
- **PROCESS EVALUATION/RESEARCH PLANNING (PERP)** -- Nexant's premier technology evaluation subscription service prepared several reports in the last few years on gas to liquids: Developments in Natural Gas to Liquid Fuels Conversion; Advances in Fischer-Tropsch Technology; Methane Conversion to Olefins and Liquids.
- **GAS-BASED CHEMICALS AND FUELS: GLOBAL PROSPECTS TO THE YEAR 2000** -- An industry analysis that quantified the likely scale of gas/gas liquids-based investments in the 1990s and assessed the potential impacts upon industry structure and pricing. The major focus was on the economics of gas and gas liquids conversion and the implications for current project planning. The study addressed the following: the potential for gas and gas liquids conversion projects based on an overall market/economic assessment of the possible products; the likely capacity of new gas and gas liquids projects and their competitiveness; and the likely impact of gas and gas liquids based developments on the supply and pricing of the relevant products. Key issues covered included: resource base (gas and gas liquids), market potential (potential products), technology (new versus improved), production and shipping economics (competitiveness and profitability), investment intention (countries and capacity development) and strategic assessment (impact, opportunities and threats).
- **LPG AVAILABILITY AND PRICING** -- Global analysis of LPG availability from a variety of sources, LPG pricing and the demand for LPG in all significant end-use markets. Forecast supply/demand balances provided the basis for projecting prices, after having also considered various political/economic factors including how LPG was priced by overseas producers and how U.S. governmental policies and programs affect global LPG markets.
- **AMMONIA BUSINESS** -- Nexant evaluated the impact of changing economics and markets on the global ammonia business, especially the effect on U.S., West European and Japanese industry trends towards fertilizer self-sufficiency in the developing world. The study also covered export-oriented production of ammonia, urea and other fertilizers by the gas-rich countries. Detailed production economics were produced for all types of feedstocks, as applicable for various parts of the world.