

CHEMSYSTEMS® PROSPECTUS

Plants to Plastics Can Nature Compete in Commodity Polymers?



CHEMSYSTEMS® PROSPECTUS January 2012 Plants to Plastics Can Nature Compete in

Commodity Polymers?

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Throughout most of human history, plants, crops, and animals have provided for the majority of human economic needs, from food energy, cooking, and heating fuels, to durable goods such as clothing and furniture. Most of these needs have shifted towards fossil fuels and petrochemicals in the past, primarily driven by cost competitiveness. There have been concerns over the increasing demand and declining reserves of fossil fuels. As a result, society is considering returning to more bio-based sources of fuels and materials. These growing concerns about carbon footprint and sustainability have some of the world's bigger players in energy and the petrochemicals industry seeking to begin using new feedstocks and products derived from renewable sources.

As a consequence of growing energy and hydrocarbon demand, and difficulties and delays in identifying and bringing on-line new sources of supply, global oil prices have reached unprecedented levels. After peaking at almost \$140 per barrel in 2008, prices fell sharply in the face of the global financial crisis crude. Crude oil prices have since rebounded to above \$100 dollars per barrel again, which has acted as a catalyst to this on-going movement toward renewable sources. Broad concerns about the future of the global economy and the natural environment have brought about a new goal for industries, consumers, and governments to strive toward in the twenty-first century: sustainability. For years, environmental and conservation groups have been the primary proponents for decreasing consumption of non-renewable resources and reducing pollutant emissions. Academic and political voices have also entered the discussion. With crude oil once again at or above \$100 per barrel interest, and perhaps there to say on a longer term basis, the investment and manufacturing sectors are now becoming much more serious about bio-based chemicals. Nexant has noted a very substantial uptick in serious investments in the development and implementation of programs for bio-based chemical opportunities. These factors have driven the development of bio-based chemicals technology to the point of practical bio-based chemicals and polymer projects worldwide.

Figure 1.1 Bio-Based Polymers and Chemicals Can Help Producers Reduce Carbon Footprints



Biofuels and bio-based chemicals have been widely promoted as a potential solution for dependence on petroleum. They also have favorable GHG (greenhouse gas) emissions compared to fossil fuels and petrochemicals, because any carbon sourced from biomass can be directly traced to atmospheric carbon dioxide (CO_2) via photosynthesis. In addition, because of the

increased emphasis on lifecycle analysis for both economic and ecological factors, industry players are becoming increasingly familiar with the details of bio-feedstocks. As an industry expert, Nexant has developed extensive knowledge in this area.

As illustrated in the following figure, global commodity polymer demand continued to grow between 2000 and 2007. After a slight dip in recent years due the economic downturn, consumption is expected to continue to grow over the next 10 years, providing an opportunity for bio-based polymers to enter the market and potentially continue to show strong growth.



Figure 1.2Global Commodity Polymers Demand
(Thousand Tons)

Many producers, especially in high cost locations, have been looking for lower cost feedstocks in places like the Middle East, or are considering alternative feedstocks such as bio-based sources. With virtually all Middle East ethane allocations already apportioned for petrochemical projects, a portion of the next wave of new ethylene may well be from bio-based sources which can emerge from strong agriculture based economies such as in Brazil, the United States, or India.

Illustrated in the following figure, oil prices over the last few years have reached historic highs, exceeding the \$100 per barrel mark twice since 2007. Oil prices hit an all-time high during the summer of 2008, when prices surpassed \$130 dollars per barrel, and after a significant drop, oil prices crept back up exceeding \$100 dollars per barrel again early in 2011. This behavior has instilled fear that the future could hold the reality of a high oil scenario maintained at levels never seen before for an extended period of time.



As illustrated in the following figure, there are many conventional routes to polymers that can be integrated with bio-based feedstocks to either supplement or replace current petrochemical feedstocks.

Nexant has outlined and analysed technologies that can help companies utilize more bio feedstocks. This report provides a comprehensive comparison of the technology, economics, and potential markets for polymers produced via renewable sources versus petrochemical sources, with an emphasis on examples such as the following:

- **Bio-ethanol dehydration to ethylene** a 40-year old commercial technology offered for license by Scientific Design Co. (SD) and by Chematur of Sweden, represented in North America by Weatherly, Atlanta, GA.
- **Bio-based "green propylene" and other "green" commodity polymers** most often can be made by adapting conventional petrochemical routes, albeit perhaps less common ones, for example, metathesis.
- **Bio-propylene has a few alternative routes**, including:
 - Metathesis is a common process to react butylene with ethylene to make propylene; bio-butanol dehydration to butylenes metathesized with bio-ethylene
 - Bio-ethylene dimerization to butylenes metathesized with bio-ethylene to make bio-propylene
 - Bio-based propane dehydrogenation
 - Fermentation to propanol followed by dehydration





Figure 1.5 Green Propylene

- The three leading commodity polymers in the market all grades of PE, PP, and even PVC, are highly relevant to large volume applications, and can all potentially be made by bio-based routes. That is, finished bio-polymers can potentially be made that will be indistinguishable from the best performing conventional polymers, but whose carbon content is completely sourced from green plants or biomass.
- **Bio-based PET**, can be produced by adapting conventional petrochemical routes using PTA and MEG, both of which can be produced via bio-based routes. Bio-based PTA can be made from *para*-xylene via BTX process from renewable feedstocks. Bio-based MEG can be produced via conventional ethylene oxide route using bio-ethylene.

This study provides the background to understand the fundamentals of bio-based feedstocks, but more importantly, how that can impact downstream polymer production.

The study was published in December 2011. The cost of the study is US\$20,000.00 (twenty thousand U.S. dollars).

This study's objective is to assess the technical, commercial and economic status of producing polymers from renewable sources. Chemical intermediates produced in this fashion could significantly supplement petroleum feedstocks going forward. The study considers critical elements of the bio-feedstocks supply chain in developing its conclusions.

This report covers:

- Bio-based technologies for the production of feedstocks and intermediates leading to the commodity polymers: PE, PP, PVC, and PET
- New technological developments
- Compare economics and cost competitiveness of bio-based routes to conventional routes
- Commercial status of green polymers
- Market outlook for the commodity polymers

The study addresses the competitiveness of current and emerging production routes, with respect to a range of technical and economic assumptions, including: different feedstocks, feedstock prices, scale factors, and policy incentives (taxes, subsidies, and other). Resulting production costs were compared to conventional polymers economics.

Technology Coverage

The report analysed technologies that cover the whole range from feedstocks and intermediates, downstream to commodity polymers. Bio-routes to the commodity polymers were assessed and compared to conventional routes currently used in industry in order to provide a comprehensive cost competitiveness analysis.

Geographical Coverage

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

- United States
- Western Europe
- Asia Pacific
- Brazil

Feedstock Coverage

The primary feedstocks covered in the study are:

- Corn
- Sugarcane
- Cassava
- Wheat
- Biomass (Wood Chips)

Olefin Coverage

The olefin intermediates covered include:

- Ethylene
- Propylene

Other Intermediate Coverage

The other intermediates covered include:

- Ethylene Glycol
- para-Xylene
- PTA

Polymer Coverage

The polymers covered include:

- Polyethylene (HDPE)
- Polypropylene (Homopolymer)
- PET
- PVC

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- 1 List of Abbreviations Used in this Report
- 2 Cost Data

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

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

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

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

Nexant's ChemSystems Simulator

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

The integrated *ChemSystems* Online[®] Simulator simultaneously develops forecasts of regional consumption, production, imports, exports and inventory changes for all commodity petrochemicals in all countries/regions.

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



Figure 4.1 *ChemSystems* Simulator Simplified Logic Diagram

It is integrated from end-use markets back to petrochemical feedstocks. It considers intermaterial competition, inter-regional price relationships, chain margins, product substitution, logistic costs and trade drivers. Costs and prices are integrated from crude oil, natural gas and petrochemical feedstocks through MEG to downstream products. One of the functional blocks depicted in the graphic above is expanded below to illustrate the interconnectivity of these drivers and the complex relationships that are built into the Simulator algorithms.





Section 5

5.1 BACKGROUND

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

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

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

5.2 DESCRIPTION OF SERVICES

Nexant's *ChemSystems* Group is now a part of Nexant's Energy and Chemical Consulting (E&CC) Division. Nexant is a specialist, not a generalist company. Our area of expertise is the energy and process industries, including oil refining, natural gas, petrochemicals, polymers, chemicals, pharmaceuticals and fertilizers. Our business has been built upon providing broad management consultancy services to leading companies active in these industries, and also to banks, suppliers, governments and others interested in these sectors.

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

5.2.1 Technology/Economics

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

Services include:

- Economic and financial analyses of projects or businesses
- Valuation of assets or businesses
- Technical audit of existing facilities
- Project feasibility/planning
- Technology innovation and assessment
- Comparative/competitive technology audit and appraisal
- Process design and cost estimation
- Technology availability, screening, licensing arrangements
- Contractor pre-qualification, evaluation and selection
- Project management, including resident advisory services
- Price, margin and profitability forecasting

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

5.2.2 Commercial

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

Services include:

- Feedstock and product market analysis
- Marketing and market research
- Supply/demand analysis and forecasting
- Studies of trends and future markets
- "Benchmarking" of costs and competitiveness
- Medium- and long-range planning

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

5.2.2.1 Strategic Planning

Industry specific expertise and an understanding of world market forces distinguish Nexant's work in Strategic Planning. Various innovative tools and methodologies tailored to the energy and process areas are used to challenge conventional thinking. Nexant extends its traditional project team approach to engaging clients directly in the Strategic Planning process. Interactive client consultant relationships promote consensus, a critical factor for successfully developing pragmatic, implementable solutions.

Services include:

- Definition of corporate and business visions
- Portfolio planning
- Entry strategy evaluation
- Diversification, acquisition, divestment studies
- Competitive analysis and business positioning
- Global competitiveness
- Trade flow and impact studies
- Strategic options, selection and implementation

5.3 ASSIGNMENTS UNDERTAKEN WHICH COVER BIO-CHEMICALS AND FUELS

5.3.1 Multiclient Work

During the past five years, Nexant's E&CC division has completed a number of major multisubscriber studies. Selected studies which included coverage of biofuels 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 Process Evaluation/Research Planning (PERP) reports, 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.

Nexant's E&CC division has also completed a number of definitive studies on specific regions. These studies have analyzed the business structure and opportunities for many of the chemicals covered in this proposed study within the context of a changing economic environment. In addition to these studies, Nexant's E&CC division maintains a global commercial and technoeconomic database covering the principal petrochemicals, intermediates and polymers.

5.3.2 Single Client Studies

- 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 was a broad-based study for the National Corn Growers Association (NCGA), funded by the U.S. DOE, to identify and screen chemicals that could be feasibly produced from corn. The study considered a wide range of potential sugars, and fermentation-derived acids, alcohols, and other building blocks, but emphasized fuel ethanol derivatives, including basic petrochemicals, solvents, intermediates and specialties, and application of the Reactive Distillation technology sponsored by the NCGA. The basic economics of ethanol production and potential improvements, economies of scale, logistics, and other production and value chain issues, are addressed in the study.
- Biodiesel Glycerine Byproduct Market Dynamics For a major U.S.-based multinational agricultural and food company with a growing stake in biofuels, Nexant analyzed the market demand/price elasticity (with a growing glut of biodiesel glycerine byproduct), existing uses of glycerine, potential substitutions for others polyols such as propylene glycol and sorbitol, and potential future applications, including reaction derivatives of glycerine in various applications and fuel uses. Nexant considered the near term and emerging and long-term market outlets for USP and other refined grades of glycerine, as well as for crude biodiesel glycerine byproduct, which is of a more problematic quality than soap and oleochemical byproduct. The study required developing views of biodiesel growth, and pricing scenarios under various assumptions.
- 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 *ChemSystems* Process Evaluation/Research Planning (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 versus 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 million to 250 million 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.
- Ethanol Project Management A Midwestern U.S. ethanol producer of corn-based gasohol retained Nexant to assist in the implementation of its 40 million gallon per year project. This included a review of the process technology and hardware provided by technology licensors and vendors. Nexant's study assisted the client to obtain Federal loans and secure bank financing.
- **"Forest Refinery" Industry Evaluation** A U.S. national laboratory retained Nexant to assess the technical and economic feasibility of a forest refinery designed to manufacture chemical products from trees. The analysis screened a variety of biomass conversion technologies and compared the production costs and energy consumption levels of each route to conventional routes. Processes evaluated included fermentation, lignocellulose separation, lignin conversion and gasification.
- Cellulosic Ethanol Feasibility Analysis A synfuels company retained Nexant to determine the technical and economic feasibility of using cellulosic feedstocks to produce commercial quantities of fuel grade ethanol. Alternative feedstocks (corn and other grains) and by-products were included in the evaluation.
- Enzyme Process Assessment Nexant assessed the impact on process economics and energy consumption resulting from substituting immobilized cells of Zymomonas Mobilis for conventional yeast in a commercial corn-based ethanol facility.
- **Fuel Ethanol Opportunity Analysis** A major oil/chemical company interested in developing fuel grade ethanol facilities in the Midwest retained Nexant to assess the competitive aspects of ethanol/gasohol. Factors evaluated included state incentive programs and change prospects, freight costs to prospective markets, and the current level of penetration of unleaded gas by ethanol.

- **European Ethanol Markets Analysis** A study for a Japanese client reviewed the West European ethanol business, including synthetic and fermentation sources. Demand, pricing, grades, end-uses, ethanol production by location and production economics were provided. In another study for this client, Nexant compared the economics of the four plants producing synthetic ethanol with the most efficient (molasses) fermentation ethanol producer.
- **Ethanol Drying** For a Japanese client, Nexant reviewed the methods used in Western Europe to dry ethanol (including fermentation sources), discussed the merits of newer technologies, and investigated international legislative actions to restrict the use of benzene or cyclohexane in azeotropic distillation.
- Ultra Clean Fuels Study For Conoco, under U.S. DOE sponsorship, Nexant performed a comprehensive review of the future for ultra low sulfur diesel (ULSD) and other considered regulatory and market drivers, petroleum distillates in transportation: production technology and economics, petroleum refining impacts, environmental/resource depletion impacts, vehicle engine and performance, consumer acceptance, distribution and refueling logistics, diesel and gasoline ICE operational issues, stationary combustors. For fuel cells: the objective was to determine the feasibility of using GTL fuels - Fischer-Tropsch distillate and naphtha and methanol (comparisons to hydrogen, ethanol and biodiesel included). At issue was the use of biodiesel as a lubricity additive to counter the reduced lubricity with loss of sulfur in ULSD and GTL.
- Synthesis Gas (Future Sources) This report reviewed the technology for production of synthesis gas (H₂, 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.
- **LNG Competition with Clean Diesel** For a multinational industrial gas company with a stake in technology for LNG as an alternative vehicle fuel/CNG refueling strategy, Nexant studied the current status of "clean diesel" (e.g., engine modifications along with ultra low sulfur diesel fuel enabling use of particulate traps and catalytic tailpipe controls to reduce soot and NOx emissions), and assessed the competitiveness of biodiesel in this context.
- Global Finished Automotive Lubricants Market Drivers For a leading U.S.-based multinational lubricants additives maker, Nexant studied the current and projected global market dynamics for finished automotive lubricants for the next two decades. Market segments/products included passenger car and diesel/heavy-duty crankcase, gear oil, automatic transmission, tractor, off-road and small engine lubricants. Fleet growth in various regions, ultra low sulfur diesel, and trends to "dieselization" of fleets in various regions were relevant issues examined. In this and other related work, Nexant has opined that a key vector for use of biodiesel, aside from as a fuel per se, will be as a lubricity

additive to ultra low sulfur diesel. Also key will be demand for biodegradable, non-toxic biodiesel fuel in small boats in place of other marine fuels.

- Synthetic-Based Drilling Fluids (SBFs) For a multinational specialty chemicals company with a stake in oleochemicals and GTL, Nexant studied market issues and projected markets for SBFs in deepwater drilling, as driven by recent U.S. EPA regulations or these oil-based systems with respect to disposal of drilling spoils (especially in the Gulf of Mexico, but in other seas as well). The only systems allowed, by consensus in a stakeholders-involved regulatory development process, are those based on Internal Olefins (IOs) and vegetable esters (essentially, "biodiesel"). These alternatives strike a balance in meeting both toxicity and biodegradability limits.
- Biodigestion of Food Wastes Nexant performed technology audits and market studies for MOM-ECAP, and another, Kuwait-based developer of projects in New York City, New Jersey and Kuwait to ferment food wastes to produce liquid and solid fertilizer/fungal disease suppressant products by the (aerobic) EATAD process of IBRC of Vancouver, BC. This also included analyses of competitive anaerobic based biodigestion technologies.
- **M2M Feasibility for Developing Economies** For USAID, Nexant studied the feasibility of capturing various streams of fugitive methane and bringing them to market ("methane-to-market", or M2M), including anaerobic biodigestion of agricultural waste biomass.
- Fatty Alcohols from Coconut Oil Project (Cebu, The Philippines) This was an extensive technical and market due diligence for a bank on the client's proposed new fatty acids/fatty alcohols plant, which involved visiting the client on Cebu, and a number of experts and oleochemicals sites in the Philippines, meetings with the process technology vendor, Lurgi AG, in Cebu and in Frankfort, Germany to review technology, flowsheets, and project budget, and performing a competitive market study (Asia and global supply/demand, prices, competition, etc.). The study included consideration of byproduct glycerine purification and disposition.
- Oleochemicals Feasibility Study For London-Sumatra's proposed new production in Indonesia, Nexant surveyed the global oleochemicals industry and markets, focusing on palm and palm kernel oils, glycerine, fatty acids, and fatty esters compared to other natural oil-based products and competition with food markets.
- **Surveys of Global Oleochemicals Markets and Technologies** Nexant addressed natural and synthetic-based oleochemicals markets for a major chemical company.

Section 6

Contact Details and Subscription Information

6.1 CONTACT DETAILS

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6.2 AUTHORIZATION FORM, TERMS AND CONDITIONS

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