ARKENOL TECHNOLOGY VALUATION

PREPARED FOR

McFARLAND GROSSMAN & COMPANY
HOUSTON, TEXAS

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McLEAN, VIRGINIA

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Prepared for
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I INTRODUCTION

Arkenol's proprietary acid hydrolysis technology converts lignocellulosic waste raw materials into value-added end-products in fuels and chemicals categories. Arkenol technology has been developed over the past five years from basic research through advanced R&D phase into a pilot-scale process that has demonstrated the successful production of commercial grade fermentable sugars in batch/continuous concentrated acid hydrolysis systems, followed by the conversion of sugars into ethanol. The company has been awarded or allocated at least four US patents on its acid hydrolysis technology and has at least fifteen other US and international patents or intellectual protection ideas pending.

Primary technology development at Arkenol was focused on ethanol production and was based on rice straw as the starting raw material. However, the company has tested several other raw material sources and researched the production of a wide variety of chemical end-products. Raw material types and/or sources that are tested at Arkenol include mixed waste (20% grass, 10% wood, and 70% paper), newsprint, green waste, grasses (switch grass and midplain grass), stover, straw, and baggass. The company has characterized all of these raw materials for sugar production. The production yield of the sugar has been further characterized into five-carbon (C5) and six-carbon (C6) sugars. Arkenol's fermentation technology for ethanol production is based on both C5 and C6 sugars derived from cellulose and hemicellulosic portions of the lignocellulosic raw materials.

This study is undertaken by Booz·Allen to determine the monetary value of collective Arkenol technologies based on its R&D base, and technology commercialization potential.

Scope of the Project

This technology valuation study is done based on Arkenol's base acid hydrolysis technology and the three first-order primary products produced from the utilization of fermentable sugars. Booz·Allen's task under this assignment was to evaluate the dollar value of Arkenol's overall technical capabilities in their core acid hydrolysis and fermentation systems as applied to three primary end-products – ethanol, butanol, and citric acid.

Booz·Allen's Task Description

Booz·Allen's specific effort under this task was focused on determining the value of Arkenol's commercial business potential in biobased fuels and chemicals markets. This task was limited to valuating ethanol, citric acid, and butanol production at full commercial scale. Based on Arkenol's identified list of targeted chemicals (both initial and long-term product lines) and the targeted consumer end-product market segments, Booz·Allen also examined both the technical soundness of technology and commercial success potential as driven by projected production costs of Arkenol's entire product line.

Booz·Allen has developed three alternate scenarios for success based on market penetration rates and potential bottlenecks for commercialization in the US domestic markets covering three time periods of present value, five year and ten year time-frames.

Study Limitations

The technology value numbers calculated in this study are based on ethanol, butanol, and citric acid economics only and do not take into consideration the influence of second- and third-order value-added chemicals that can be produced from Arkenol's technology.

This study further limits the economic calculations to the US fuel and chemical markets only. Details of the calculation methodology are explained in Section 3 below. Since the company has the most experience in fermentable sugar and ethanol production technologies, these have been evaluated under the least amount of economic constraints. The other two first-order chemicals – butanol and citric acid – are evaluated with market entry and production constraints. The R&D experience in developing these products is another constraint since it determines the confidence in the commercialization of Arkenol's technologies.

Another limitation of this study is the evaluation of market penetration rates for the three Arkenol products. The assumptions made in determining the available markets are based on the present market climate which may change dramatically with time. The present value scenario will present the most accurate value numbers with the best confidence interval, followed by the five and ten year value projections.

Disclaimer

Booz·Allen has conducted this technology valuation study based on appropriate market, business, technology, and management information that was provided by Arkenol and other external sources that are industry relevant.

Data Source Reliance

To the best of our knowledge, the data used to determine the value of Arkenol technology is supported by documentation. The primary source of technology information was Arkenol while market and business development information is from a wide variety of sources listed in the bibliography section at the end of the report. The technology information was gathered by reviewing the technical information from the documents that were supplied by Arkenol Inc., McFarland Grossman & Company, and a number of external sources (both public and propritary information to Booz·Allen during phase one of this project. Booz·Allen also interviewed key technical and business personnel at Arkenol who are responsible for research, development and commercialization of Arkenol technology.

Several industry relevant sources were utilized for base data on present market size, existing production capacities, production costs, and market growth rates. Booz·Allen has made every effort to cross-reference the information sources to ensure accuracy. However, we realize that the accuracy of information can not be absolute and hence our reliance on external sources of primary market and industry information may introduce an error element into our overall value projections. (Please see Section 5 on value adjustment considerations for further clarification on data source reliance).

During the course of this valuation study, Booz·Allen has identified 32 primary variables (both Arkenol technology specific and external industry and market factors) that could affect the outcome of this analysis. We have made assumptions based on our knowledge of the bioproducts industry, markets, and technologies to reduce the number of working variable with a minimum impact on the accuracy of the results. Key economic variables that are technology specific were homogenized for the three products under consideration so that a comparison was possible. Since these three products deal with three different market sets, it was not possible for us to perfectly align all of the market variables. For example, ethanol sells in the fuel market, butanol in industrial chemical/solvent markets, and citric acid in food/beverage and chemical markets.

Liability Clause

This valuation study was prepared by Booz·Allen & Hamilton Inc. of McLean, Virginia, for the McFarland Grossman & Co. of Houston, Texas under a consulting agreement. The material in this study reflects Booz·Allen's best judgment in light of the information available to it at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third party. Booz·Allen accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this report.

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II SCOPE OF VALUATION

The scope of this valuation is based on primary acid hydrolysis technology and the first-order product line as identified by Arkenol. The actual value determination is performed based on intellectual property of the operating, licensing, and patent sold values of Arkenol technology.

Arkenol Technology and Product Line

The Arkenol strong acid hydrolysis technology converts lignocellulosic waste materials available from agricultural and industrial sources into fermentable five- and six-carbon sugars that are then converted into value-added fuels and chemicals.

Brief Technology Description

Arkenol has invested approximately $5 million in the development of a proprietary concentrated acid hydrolysis technology that converts lignocellulosic materials to value-added industrial and consumer end-products in fuels and chemicals categories. Stage one processes the primary feedstock into fermentable sugars of both five and six carbon atoms, while the second stage of the process takes these fermentable sugars and converts them to the desired fuel or chemical end-products.

Arkenol's fermentation systems are based on fermenting both five- and six-carbon sugars to value-added end-products. This immensely adds to the overall economic productivity of the process. We have factored in this valuation the added gains that occur as a result of converting five-carbon sugars into value-added products. Conventional fermentation schemes are limited to processing only six-carbon sugar into ethanol, butanol or citric acid.

As the base case, Arkenol technology takes the primary raw material, e.g., rice straw or waste paper, and passes it through a hammer mill to physically break down the material into smaller pieces in order to increase the surface volume. Then, the finely divided raw material is sent to a decrystalizer/hydrolyzer where water and concentrated sulfuric acid is added to hydrolyze the cellulosic material into sugars and lignin. The lignin portion is recovered as a byproduct which is then used to either supply the energy needs for the process or further processed as a value-added byproduct for revenue generation. The excess acid is recovered and recycled into the process.

Small amounts of excess sulfuric acid in the sugar solution is neutralized with sodium hydroxide. The sugar solution is then fed to the fermentation unit. In the fermentation reactor, the appropriate microbial strain is added under sterile conditions. Some nutrients are added to support the microbial growth and to maximize the conversion efficiency of the fermentation process. Depending upon the type of microbe, ethanol, butanol, or citric acid is produced, which is then separated from the rest of the fermentation broth via distillation or other separation techniques. Carbon dioxide is produced as the byproduct in the

Arkenol has tested most of the available raw material sources for their suitability in the acid hydrolysis technology for the production of primary sugars including agricultural waste biomass (rice and other grain straw), pulp mill sludge, newsprint, lumber mill wood chips, saw dust, and other agricultural and industrial materials.

The flexibility of feedstock acceptance by Arkenol's acid hydrolysis technology allows the proposed biobased chemicals production systems to be adapted universally by matching locally available raw materials – waste or virgin – with the needed chemicals for meeting the market demands. Also, integration of power generation and utilization of cogeneration schemes with fuels and chemicals production lends itself to both greater energy and material efficiencies that translate into better production economics.

List of Products by Category

Fifteen chemicals have been selected by Arkenol to target in the initial phase of business development. The chemicals are divided into three categories: organic acids, solvents, and other chemicals. The table below presents the market evaluation of these chemicals based on current market forces, technology adaptability potential by Arkenol, and other domestic and international market drivers.

The chemicals selected for primary business development focus are first-order chemicals only. Several derivatives of these chemicals are possible for further development that would target both niche and specialty high-value markets. The selected list of chemicals under consideration for commercialization at Arkenol is presented in the table below.

List of Arkenol's Primary and Secondary Products

Organic Acids	Solvents	Other Chemicals
Lactic Acid	Acetone	1,4-Butanediol
Citric and Oxalic Acid	n-Butanol	Butyl Butyrate
Fumaric and Acetic Acid	Ethanol	Acetates (Ethyl and Butyl)
Gluconic and Itaconic Acid	Isopropanol	Sorbitol

Intellectual Property Valuation Basis

The intellectual property valuation done by Booz·Allen is based on the number and types of patents that Arkenol has obtained or filed on its core acid hydrolysis and fermentation technologies. The information provided by Arkenol in the form of patents, publications, and through the personal interviews with the technical and business staff at Arkenol are the basis for the intellectual property valuation component of this study.

Three different scenarios emerge when we consider the implementation of Arkenol's technology:

- Arkenol may choose to actually build and operate the production facilities.
- Arkenol may choose to license its technology to other companies that would then build and operate commercial scale facilities.
- Arkenol may choose to sell all of its intellectual property rights and its patents.

III METHODOLOGY OVERVIEW

The methodology employed to determine the value of Arkenol technology is based on a wide variety of factors that are driven by technical, market, business, company experience, product, and other relevant factors.

Valuation Model

The valuation model is primarily based on important economic variables that are identified to have the most influence on the production economics of Arkenol technology. The generic formula used to calculate the value of each product segment is based on the following list of variables:

- Present product market size
- Market capture potential by Arkenol based on present implementation
- Production costs of Arkenol products based on fermentable sugar production technology
- Present market value of Arkenol products
- Market penetration success potential by Arkenol products
- Value of Arkenol intellectual property based on patents owned and applied

The above is a partial list of variables that are considered to evaluate the value of Arkenol technology under the present case scenario. The scenario model presented below explains the additional factors considered for five year and ten year scenarios.

The actual formula used to calculate the value numbers is presented below.

$$\text{Value} = \frac{\left[\begin{array}{c}\text{Total Market Size}\\ \text{(million pounds)}\end{array}\right] \text{X} \left[\begin{array}{c}\text{Target Market Size}\\ \text{(percentage)}\end{array}\right] \text{X} \left[\begin{array}{c}\text{Intellectual}\\ \text{Property Value}\end{array}\right] \text{X} \left[\begin{array}{c}\text{Processing}\\ \text{Value-added}\end{array}\right]}{\left[\begin{array}{c}\text{FAPSIM Adjustment}\\ \text{(unitless factor)}\end{array}\right]}$$

The total market size is determined based on the applicability of Arkenol's technology to various all present processes that depend upon primary C5 and C6 sugars as their starting material. The target market size is calculated based on market capture potential for Arkenol technology within commercial economics of competing production processes such as corn sugars and other available raw materials that compete with the lignocellulosic feedstocks used by Arkenol technology.

The value of intellectual property as determined by the number of patents issued and pending, and the quality of technical and management staff of the company is factored into this valuation. The value added factor based on processing of low value (or zero or negative value) raw material into C5 and C6 sugars is one of the key factors that determine the total value of the company and or its technologies.

FAPSIM (The Food and Agriculture Policy Simulator) is used to quantify the economic effects of the production of significant quantities of sugars on the overall market value and the size of the biobased starting raw material. FAPSIM is an annual econometric model of the U.S. biobased sector, originally developed at the Department of Agriculture during the early 1980s. Since that time, FAPSIM has been continually re-estimated and re-specified to reflect changes in the structure of the industrial agriculture sector of the economy.

Although, FAPSIM was designed primarily as a U.S. agriculture policy and economic analyses tool, it has been expanded in the 1990s to predict the boundaries on the market penetration of new biobased products and/or technologies that depend upon agricultural commodities or wastes as raw material inputs. The model is operated solely by the Economic Research Services of the U.S. Department of Agriculture in Washington, DC. The use of this model for this study was allowed as a courtsy to Booz·Allen & Hamilton by the Economic Research Services of U.S. Department of Agriculture.

Scenario Model

The value of Arkenol technology is time sensitive. Since the technology has only been developed through advanced R&D phase into pilot-scale operation with no commercial plants currently in operation, the present value of Arkenol technology only represents the combination value from the following technology implementation levels:

- Value of Arkenol's core acid hydrolysis technology that produces fermentable sugars.
- Value of fermentation technology that results in the production of ethanol.
- Value of other first-order chemicals (butanol and citric acid only)
- Value of second-order chemicals that can be produced immediately via fermentation technology already tested for ethanol production.
- Value of intellectual property and operating experience of pilot-scale systems

The actual formula used to calculate the value numbers is presented below.

$$\text{Value} = \frac{\left[\begin{array}{c}\text{Total Market Size}\\ \text{(million pounds)}\end{array}\right] \times \left[\begin{array}{c}\text{Target Market Size}\\ \text{(percentage)}\end{array}\right] \times \left[\begin{array}{c}\text{Intellectual}\\ \text{Property Value}\end{array}\right] \times \left[\begin{array}{c}\text{Processing}\\ \text{Value-added}\end{array}\right]}{\left[\begin{array}{c}\text{FAPSIM Adjustment}\\ \text{(unitless factor)}\end{array}\right] \times \left[\begin{array}{c}\text{Scenario Market}\\ \text{Adjustment Factor}\end{array}\right]}$$

This model is based on the valuation model with scenario correction made to the markets based on FAPSIM predictions.

The five year and ten year scenarios take into consideration the increased market capture by Arkenol products, reduction in production costs, production of higher-value added products in second-order and specialty chemicals categories by Arkenol technology, and economies of scale of large scale production. The increase in markets in ten year scenario also comes from Arkenol's entry into international markets.

Technology Model

The technology model is based on the economic improvements that can be realized by improving the technical aspects of Arkenol technology. It assumes that all potential products – sugars, ethanol, first-order, second-order, and specialty chemicals – are produced from Arkenol technology using both acid hydrolysis and fermentation technologies based on experience that Arkenol has gained to date by operating the pilot-scale facility. The following are the key elements of this model:

- Pilot-scale demonstration of acid hydrolysis and ethanol production.
- Arkenol can market fermentable sugars as starting material to other industries at a cost of $0.06 to $0.08 per pound.
- Ethanol production at full commercial scale is possible within a one year time frame under present value scenario.
- The production processes for the primary product line under consideration for this study are optimized.

The actual formula used to calculate the value numbers is presented below.

$$\text{Value} = \frac{\left[\begin{array}{c}\text{Total Market Size}\\ \text{(million pounds)}\end{array}\right] \text{X} \left[\begin{array}{c}\text{Target Market Size}\\ \text{(percentage)}\end{array}\right] \text{X} \left[\begin{array}{c}\text{Intellectual}\\ \text{Property Value}\end{array}\right] \text{X} \left[\begin{array}{c}\text{Processing}\\ \text{Value-added}\end{array}\right]}{\left[\begin{array}{c}\text{FAPSIM Adjustment}\\ \text{(unitless factor)}\end{array}\right] \text{X} \left[\begin{array}{c}\text{Scenario Market}\\ \text{Adjustment Factor}\end{array}\right] \text{X} \left[\begin{array}{c}\text{Technology Model}\\ \text{Adjustment Factor}\end{array}\right]}$$

The technology model is applied to both present value and scenario models in the overall valuation of Arkenol's technology. However, the present value numbers presented do not include any inclusion of the scenario model. The technology levels considered under these models are as follows:

- Base technology (acid hydrolysis technology producing fermentable sugars)
- Ethanol production technology (fuel market only)
- First-order chemicals (chemical market only)
  (limited to butanol and citric acid for this study)
- Second-order chemicals (chemical market only)
- Specialty chemicals technology (chemical market only)

In addition to base chemicals production considered under present value scenario (ethanol, butanol, and citric acid), under the five year scenario, increased production of second-order chemicals is assumed, and under the ten year scenario, production of specialty chemicals is assumed.

IV VARIABLE MODEL ASSUMPTIONS AND VARIABLE SENSITIVITY

This valuation study identified 32 variables that influence the economics of the overall production scheme of Arkenol technology. We have made assumptions wherever possible to simplify the model.

Variable Sensitivity Analysis

We have paid especial attention to variables that are sensitive to external factors, such as raw material costs, market growth rate projections, Arkenol market share projections, and product yields based on present technical and potential improvements of Arkenol technology. The following graph presents the sensitivity ranking of variables that are considered in this analysis.

The price sensitivity to overall economic value of Arkenol technology is one of the most important factors identified in this analysis. The overall value of Arkenol technology can change by as much as 30-35 percent depending upon production costs associated with ethanol and first-order production systems. This sensitivity decreases with increases in the value-added component of the product mix. With time, the risk associated based on production cost data decreases as more second-order and specialty chemicals are produced.

Principal Economic Drivers

Principal economic drivers influencing Arkenol's product line in ethanol, butanol, and citric acid markets are based on aggregate market size, market growth rates, potential for market capture by Arkenol, and the price projections of each of the three product types. The following table presents the present market size, growth rates and projected market share capture potential for Arkenol under two scenarios.

Market Size, Growth Rates and Projected Market Shares of Arkenol Products

Arkenol Product	Present Market Size (million pounds)	Present Market Growth Rate (percent)	Arkenol Market Share Potential (5 years)	Arkenol Market Share Potential (10 years)
Ethanol	11,000	5-6	20-25	40-50
Butanol	1,250	4-5	8-10	20-25
Citric Acid	475	5-6	10-12	25-30

The present selling price of Arkenol identified chemicals is slightly higher than historical prices due to increased costs for feedstocks from which the conventional products are made. Corn is used to produce almost 95 percent of ethanol and over 90 percent of citric acid. Almost all of the butanol produced today comes from crude oil derived butylene.

Ethanol currently costs between $1.30 and $1.45 per gallon. Recent corn-based citric acid prices have ranged between $0.85 and $1.04 per pound. Butanol selling prices have been between $0.50 and $0.55 per pound. The following table compares the present product

costs/prices with Arkenol projected production costs for these products in the present, five year, and ten year time frames when the economy of scales and increased market shares are realized.

Present Prices and Projected Arkenol Production Costs Under Different Time Scenarios

Arkenol Product	Present Selling Price (cents per pound)	Present Arkenol Production Costs (cents per pound)	Arkenol Production Costs in 5 years (cents per pound)	Arkenol Production Costs in 10 years (cents per pound)
Ethanol	18-21	10-12	7-9	5-6
Butanol	50-55	30-35	25-30	20-25
Citric Acid	85-104	65-70	55-60	50-55

The data presented in the table above is primarily used in the valuation models to predict the value of Arkenol technology. A weighted average is used for determining the aggregate market share of Arkenol in these three product categories combined.

V VALUE ADJUSTMENT CONSIDERATIONS

The values presented in this study are based on the Technology Model which assumes Arkenol is operating as a fully integrated chemical manufacturer and distributor. Since Arkenol is currently a development company, certain factors should be considered in assessing the relative values presented in this study. These factors are identifiable, but are not quantifiable, and therefore have not been included in the valuations presented in this study. Although it is important to note these factors, their ultimate impact on the valuation is limited. Following is a discussion of the four major factors:

- The ability to scale-up the technology from a pilot plant level to a full size plant. Arkenol has built, tested and operated a chemical plant and Arkenol's management has substantial experience in scale-up and commercialization of other types of facilities and technologies. However, they have not built a full size operating plant for their specific technology. Arkenol has secured process guarantees and had multiple engineering firms confirm that the plant can be scaled-up to a full size operating plant.

- Existing or future competing technologies and products. It is difficult to predict future technologies or entrants into the three identified Arkenol markets. However, Arkenol is aware of similar technologies that are in various stages of development. Few, if any, of these technologies are as advanced as Arkenol's and are not as competitive from a cost perspective. Arkenol has purchased a broad patent approach to protect its intellectual property and has one patent issued, three allowed and three pending.

- Arkenol's lack of marketing and distribution capabilities. The ability to meet sales levels identified in the valuations is dependent upon marketing and distributing the product. As a development company, Arkenol does not have a marketing or distribution infrastructure. Arkenol recognizes this issue and has identified several executable strategies to address this factor including acquiring an existing marketing company.

- Lack of management experience in the chemical industry. Arkenol's management reflects the fact that they are a development company and not an operating chemical company. Arkenol would need to add management with significant experience in the chemical industry to achieve the revenues and valuation presented in this study. There is no indication that it would be difficult to identify and hire these individuals.

VI RESULTS AND CONCLUSIONS

Booz·Allen estimates the present value of Arkenol's technology in the range of $385 to $540 million based on the present value model. This value set is not discounted based on value adjustment considerations. A complete breakdown of this analysis is presented in the table on the following page.

Under Scenario II with the five year growth model, Booz·Allen estimates the value of Arkenol's technology to be in $860 to $1,235 million range. Under Scenario II considering a ten year growth model, our estimates of the value of Arkenol technology ranges between $1,750 to $2,400 million.

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Valuation of Arkenol's Technology Based on Primary Acid Hydrolysis and Fermentation Technologies for the Production of C5-C6 Sugars, First-, Second-Order, and Specialty Chemicals Under Different Growth Scenarios

Technology Level	Scenario I (present value) (million dollars)	Scenario II (5 years) (million dollars)	Scenario III (10 years) (million dollars)
Base Technology (Acid Hydrolysis-Sugar Production)[1]	$170-$230	$205-$290	$400-$550
Ethanol Production Technology (fuels market only)[2]	$180-$255	$310-$450	$480-$675
First-Order Chemicals (chemical market)[3]	$30-$45	$295-$420	$580-$700
Second-Order Chemicals (chemical market)[4]	$5-$10	$50-$75	$220-$375
Specialty Chemicals Technology (chemical market)[5]	—	—	$70-$100
Total Technology Value (all markets combined)	**$385-$540**	**$860-$1,235**	**$1,750-$2,400**

SOURCE: Booz·Allen & Hamilton Inc. calculations based on data obtained from and interviews performed at Arkenol Inc., and also from other information sources on markets, technology, research in the related industry, McLean, Virginia, July 1996.

1 Based on demonstrated viability of acid hydrolysis technology, number of patents issued, process economics, feedstocks evaluated in pilot-scale production, and projected sugar production costs. Other factors taken into consideration in this calculation include technical and management staff experience, industry interest in Arkenol's technology, number of project developments, and market growth scenarios/application potential for base technology in chemical industry.
2 Based on market capture potential in domestic and international fuels markets. Factors taken into consideration include historical, present, and projected market growth rates in domestic and international markets, ethanol industry production capacity expansion commitments in the private industry and government efforts for infrastructure building for alternative fuels.
3 First-order chemicals that are primarily considered under scenarios I and II include industrial ethanol, n-butanol, and citric acid only. Under scenario III, a list of over 15 organic acids and solvents are considered as listed in Arkenol's business plan for 14 targetted end-products market segments.
4 Second-order chemicals considered in this valuation are both primary and secondary chemical derivatives of first-order chemicals produced by Arkenol's technology based on market growth potential projected by the chemical process and the consumer end-products industries.
5 High-value low-volume chemicals. Only those specialty chemicals are considered that are complementarily produced with first- and second-order chemicals.

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