SYNOPSIS OF THE FINAL REPORT ON:

Assessment of the blending value of bio-ethanol with local and imported petrol

Confidentiality Statement

The data, results and models culminating from the Bio-ethanol determination study are the property of the Department of Energy, South Africa, and may not be quoted, copied or transmitted in any form without permission.

Individual oil company commercial data, P&ID's and refinery linear programming results are subject to confidentiality agreements between the company and Dynamic Energy Consultants and Infinergy Consulting. **Only aggregated bioethanol blend values and capital and operating costs are contained in the Final Report.**

Acronyms and Definitions

API gravity	American Petroleum Institute gravity
BFP	Basic Fuel Price in SA cents per litre
BOB	Blendstock for Oxygenate Blending
DAS	Duty At Source
E2	Petrol blends containing up to two percent by volume of ethanol
E5	Petrol blends containing up to five percent by volume of ethanol
E10	Petrol blends containing up to ten percent by volume of ethanol
FVI	Flexible Volatility Index = RVP + 0.70*E70(%evaporated at 70^{o}C)
HMU	Hydrogen Manufacturing Unit
IFQC	International Fuel Quality Centre
LP model	Linear Programming model
MTBE	Methyl Tertiary Butyl Ether
MON	Motor Octane Number
NAAMSA	National Association of Automobile Manufacturers of South Africa
NMPP	New Multiproduct Pipeline owned by Transnet Limited
NPV	Net Present Value
P&ID	Piping and Instrumentation Diagram
PAM	Petrol-Alcohol Mixture
PPI	Producer Price Index
RON	Research Octane Number
RVP	Reid Vapour Pressure in kPa
SAPIA	South African Petroleum Industry Association
TAME	Tertiary amyl methyl ether
VROOM	Very Rough Order of Magnitude
Hydrocarbon Blending Value	The value of bio-ethanol as a petrol blend component to a blender, which is dependent on the basic petrol price and can be expressed as a percentage of the unleaded petrol 95 BFP
Bio-ethanol	An ethyl alcohol derived from plant material and used as a blendstock for petrol
Brownfields site	An existing installation with infrastructure and services

1. INTRODUCTION

Energy Consultants and Infinergy Consulting were commissioned by the Department of Energy to assess the blending value of bio-ethanol with local and imported petrol. The objective of this study was to determine a blend value of bio-ethanol, which incorporates all the costs incurred and the benefits gained by local petroleum companies were bio-ethanol to be blended at 2%; 5% and 10% by volume, such that cost neutrality is maintained.

In a typical oil refinery operation, petrol contains multiple components in an optimised blend to meet the required petrol specifications. Introducing bio-ethanol into a blend contributes benefits and penalties to the blend pool value. Bio-ethanol has a significantly higher research octane number, adds oxygen to a blend, contains zero benzene and aromatics, and has low sulphur content, which increase its hydrocarbon value relative to petrol. It is also a locally-manufactured replacement for high-octane petrol and component imports. However this value of bio-ethanol is diminished mainly due to its adverse properties of lower motor octane number response and high volatility. As a result of high non-linear blending volatility of bio-ethanol, the petrol blending process is forced to discard other high-value, high-volatility components like butane, pentane and isomerate. The net effect of bio-ethanol blending on refinery margins is its hydrocarbon blend value relative to unleaded 95 octane petrol.

Due to the high volatility and hygroscopic nature of bio-ethanol, oil companies would need to invest in new, separate fixed roof tanks, advanced fire-fighting systems and enhanced housekeeping and control systems. Special wastewater management systems, receipt, storage, blending and loading facilities, as well as satellite laboratories would be required for depot blending. These additional capital and operating costs have been considered in establishing cost neutrality.

The study was carried out in four phases over six months, as follows:

- **Consultation and Alignment**: Engagement with oil company CEO representatives. Presentation of project objectives. Agreement on support for the study, use of companies' LP models and allocation of LP specialists and project engineers.
- **LP modelling and analyses**: Refinery LP modelling and analyses of 2%, 5% and 10% bio-ethanol blends with Euro 2 petrol. Run waiver cases and sensitivity cases. Establish aggregate hydrocarbon blend value. Determine scope of capital modifications.
- **Financial Modelling**: Generate capital estimates. Develop financial model to allow users to calculate the aggregate bio-ethanol blend value relative to unleaded 95 petrol for various cases.
- **Reporting**: Write an interim and a final report on analyses, provide financial model and manual. Train users on how to operate and update model when required.

Hydrocarbon blend values for bio-ethanol blends of 2%; 5% and 10% with and without RVP and FVI fuel specification waivers were calculated using linear programming work done bilaterally with the oil companies in South Africa. The results were analysed, compared and aggregated. The hypothesis that a heavier crude diet would increase bio-ethanol hydrocarbon blend values was tested. New opportunities for increasing bio-ethanol blend values were identified during this process, such as the potential benefit of removing the 2-point MON penalty on petrol containing bio-ethanol. These have been included in the analyses.

From consultation with the individual oil companies and guidance of a third-party project management company with a petroleum depot construction portfolio, the scope and cost of capital changes were established at a pre-feasibility level. Scenarios for minimum, most likely and maximum capital and operational expenditure were generated.

A financial model was developed in Microsoft Excel to combine all the relevant cost and benefit effects of bio-ethanol, and to calculate the aggregate blending value automatically as a differential to the unleaded 95 petrol Basic Fuel Price for different scenarios. The model has been designed to be simple and user-friendly, allowing data to be amended should the underlying assumptions change.

2.1 Bio-ethanol Blending in Petrol

2.1.1 History

Ethanol is not a new fuel. In the 1850s, ethanol was a major lighting fuel in the United States. During the North American Civil War, a liquor tax was placed on ethanol to raise money for the war. The tax increased the price of ethanol such that it could no longer compete with other fuels, such as kerosene in lighting devices. Ethanol production declined sharply because of this tax and production levels did not begin to recover until the tax was repealed in 1906.

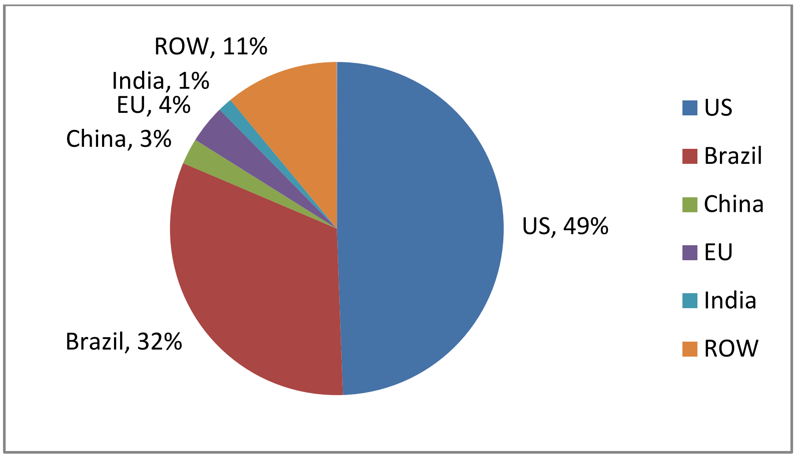
In 1908, Henry Ford designed his Model T to run on a mixture of gasoline and alcohol, calling it “the fuel of the future.” In 1919, when Prohibition began, ethanol was banned because it was considered liquor. It could only be sold when it was mixed with petroleum. With the end of Prohibition in 1933, ethanol was used as a fuel again and its use increased temporarily during World War II when oil and other resources were scarce. In the 1970s, interest in ethanol as a transportation fuel was revived when embargoes by major oil producing countries cut petrol supplies. Since that time ethanol use has been encouraged by offering various tax benefits for producing ethanol and for blending ethanol into petrol.

In 1988, ethanol began to be added to petrol for the purpose of reducing carbon monoxide emissions in North America as ethanol is an oxygenate. Demand for ethanol increased when MTBE (an alternative oxygenate) was banned in 2000 due to the discovery of trace amounts of MTBE in the ground water.

Brazil was the world leader in fuel ethanol production and utilisation until 2005. Since then the US has consistently produced more ethanol each year than Brazil. The Brazilians use sugar cane as the primary feedstock to produce up to 50% of the nation’s automotive fuel.

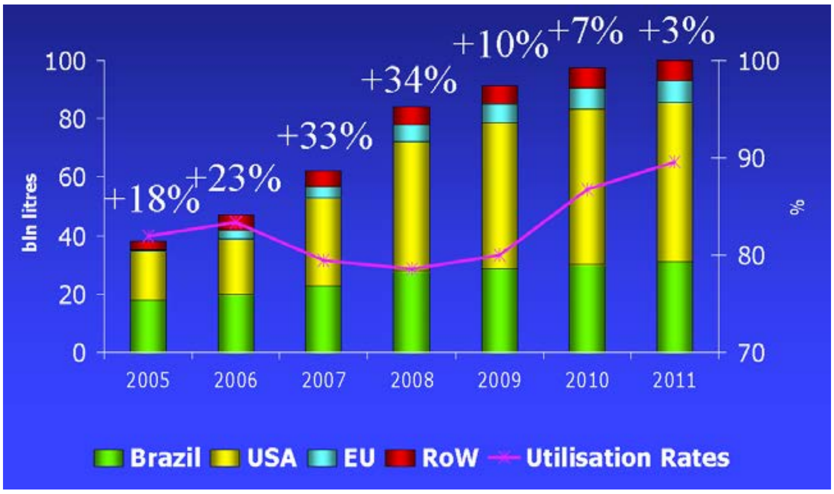
2.1.2 World Production and Consumption of Bio-ethanol

The geographic basis of world production of fuel ethanol in 2009 is shown in Figure 1 (total 80 million tonnes). The US accounts for about half of world production (from grains) with Brazil as the second largest producer (from sugar cane). Figure 2 shows the increase in capacity over the last seven years, as well as capacity utilisation.



Data source: F O Licht

Figure 1: World Production of Fuel Ethanol in 2009



Source: F O Licht

Figure 2: World Capacity and Utilisation of Fuel Ethanol

World production, consumption and export history of bioethanol are given in Figure 3, which also shows forecasts of demand.

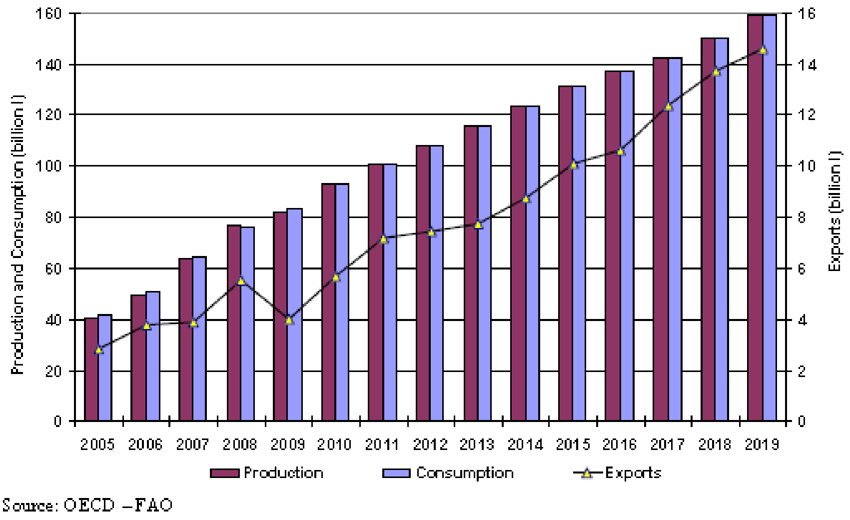


Figure 3: World Bioethanol Balance

There are five manufacturers of fermentation ethanol in South Africa and Swaziland, based on molasses as the feedstock. The product is used in industrial and commercial applications, e.g. liquor industry, solvent applications, pharmaceuticals, etc.

Company	Annual Capacity (m^3)
NCP	55,000
Illovo	48,500
Royal Swazi	45,000
Glendale	5,000
USA Distillers	32,000

In addition, Sasol produces synthetic ethanol from the Fischer-Tropsch process at Secunda. Some of this ethanol is blended into the synthetic petrol produced at Secunda (less than 2% inclusion). There are also a number of other small manufacturers.

In South Africa, construction of the first dedicated fuel bio-ethanol manufacturing plant is scheduled to commence in 2012 in Cradock in the Eastern Cape. It will produce 90 million litres per year of bio-ethanol from sorghum as a first phase. Other potential plants in South Africa are in feasibility study stage.

3. Bio-ethanol Manufacturing Process

3.1 Ethanol is produced by fermentation, a biological process in which sugars such as glucose, fructose and sucrose are converted into cellular energy and thereby produce ethanol and carbon dioxide as metabolic waste products. Because yeasts perform this process in the absence of oxygen, ethanol fermentation is classified as anaerobic. The chemical equation below summarises the conversion:

$$C_6H_{12}O_6 \rightarrow 2\ CH_3CH_2OH + 2\ CO_2$$

The process is carried out at around 35–40 °C. Ethanol's toxicity to yeast limits the ethanol concentration obtainable by brewing. The most ethanol-tolerant strains of yeast can survive up to approximately 15% ethanol by volume.

To produce ethanol from starchy materials such as cereal grains, the starch must first be converted into sugars. The hydrolysis of starch into glucose can be accomplished by treatment with dilute sulphuric acid, fungally-produced amylase, or a combination of the two processes.

3.2 Integration of Bio-ethanol Within Refinery Operation

Petrol is a multi-component mixture of several refinery steams blended to meet a specification. A typical breakdown is shown in Figure 4.

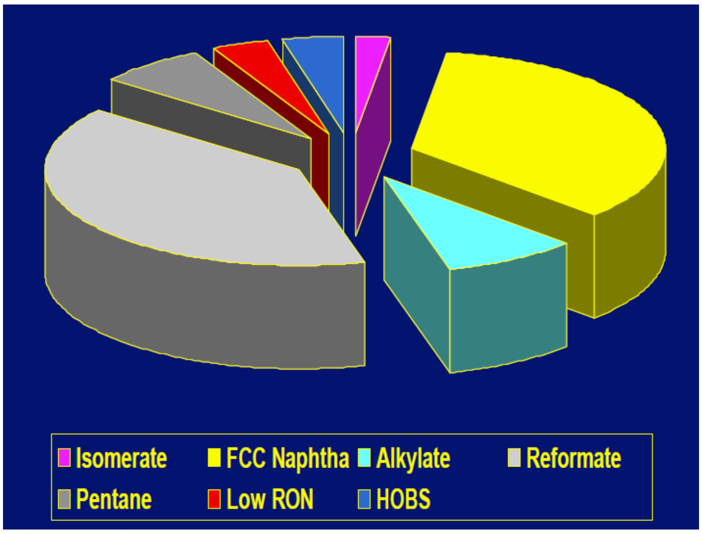


Figure 4: Typical Composition of Petrol

3.3 Ethanol has multiple benefits to refiners in a petrol blend:

- *Delivering octane and oxygen*

Ethanol is a high octane oxygenate, with a blending octane (RON) of approximately 114-129. To a refinery, these properties, in combination with an alternative supply chain, are valuable additions to the flexibility of refineries. Ethanol offers a means to increase blend octane levels without further upgrading of petroleum distillates. However, the downside includes the need for additional tankage, managing geographic differentiations, product mix changes and optimisation across multiple facilities.

The addition of alcohol to petrol can be beneficial in high altitude areas as the ethanol compensates for the oxygen loss because of the less dense air at high altitude. With necessary infrastructural changes, ethanol could be accommodated in South Africa as per the current SANS specifications which allows for a maximum of 7.5% ethanol at the coast and 9.5 % inland in the absence of any other oxygenates. Mixtures of oxygenates will be controlled by the maximum oxygen content as per the SANS specifications for both inland and at the coast.

- *Adjustments to the base petrol*

In net export or balanced regions, ethanol offers an alternative to blending high-octane isomerate and reformate, produced by converting low-octane naphtha streams in an isomerisation unit and a reformer, respectively, which are typically added to meet the octane requirements. Consequently, refiners can increase the percentage of low-octane naphtha in the petrol blend and reduce the isomerisation unit and reformer throughput. Since the conversion of naphtha to isomerate and reformate results in petrol volume loss as hydrogen and other low-value light components are produced as by-products, less processing results in higher yields of fossil petrol per barrel of crude oil. This benefit may be fully realised when the refinery has a HMU unit or an external source of hydrogen for diesel desulphurisation. Alternately, in a region that is a net importer of high-octane components and petrol, ethanol can displace imports of these components.

- *Aromatics, benzene and sulphur reduction*

Ethanol contains zero aromatics and benzene, and can aid the reduction of benzene levels to 1% without refinery investment, and partially offset expensive refinery investment required for aromatic and sulphur reduction.

- *Fuel import replacement*

South Africa is structurally short of refined petroleum product capacity and large quantities of petrol (ULP95) are imported, with the import volume predicted to grow over the next few years until additional refining capacity is built in the country. As long as the volatility specifications of petrol-alcohol mixtures (PAM) do not force out significant quantities of light components, such as butane, indigenous supply of ethanol can increase the petrol pool and displace an equivalent amount of imports of ULP95. Besides less risk of uncompetitive import pricing, this would have favourable impacts on working capital for refiners.

The total volume of petrol produced during ethanol blending decreases until about 7 vol % blending. Thereafter it increases, but not in proportion to the volume of ethanol blended. Each blend of petrol will have a different volume response, but as long as the volatility specifications remain at current levels, the total South African petrol pool will not increase by the volume of ethanol blended. This provides a strong case of relaxation of the RVP and FVI specifications.

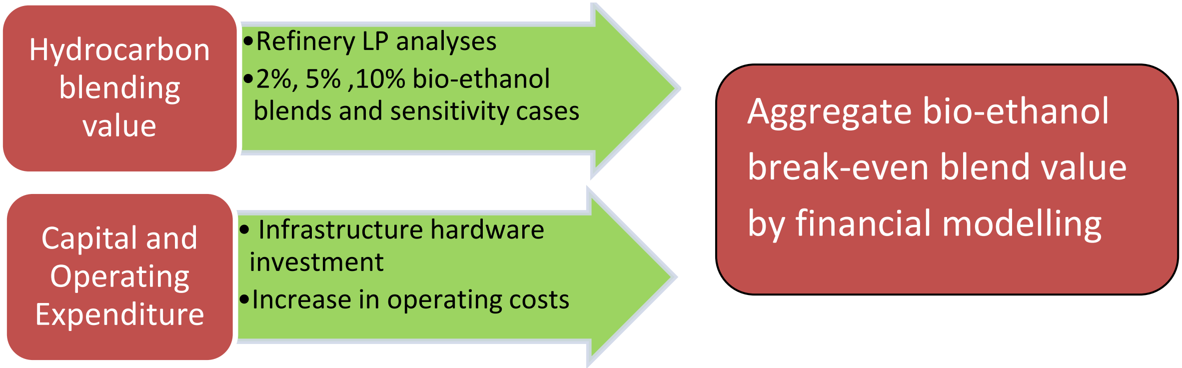
While ethanol has advantages for refiners, it also introduces a number of challenges:

- Volatility increases;
- Impact of backing out light components;
- MON penalty;
- Hygroscopic nature of ethanol;
- Distribution issues;
- Fungibility issues;
- Fire danger;
- Market complaints; and
- Quality assurance

The above issues ideally require that ethanol addition to petrol occurs as far down the supply chain as possible, i.e. at the distribution terminals. Refineries situated in their main markets and with dry infrastructures may be able to distribute directly. This will require investment in ethanol storage facilities and injection equipment at these terminals or refineries

Blending of bio-ethanol into local and imported petrol in South Africa would have penalties or benefits on oil refinery margins due to the chemical properties of bio-ethanol and the unique configuration and operating conditions of each refinery. Oil companies that blend bio-ethanol into petrol either at depots or refineries for the first time would need to invest in infrastructure upgrades to receive and store bio-ethanol separately, and to blend, test and dispatch the petrol containing bio-ethanol.

Therefore, the blending benefit or penalty and the cost of installing and operating new infrastructure are the two elements that determine the value of bio-ethanol relative to unleaded 95 petrol in a blend. The aggregate break-even value of bio-ethanol is the transfer price, either at a discount or premium to unleaded 95 BFP, which would compensate the petroleum industry for its related investments and take into account the value of bio-ethanol as a petrol component when blending at the refinery or depots.



4. Refinery Linear Programming and Analyses to Determine Hydrocarbon Blending Value

Linear programming is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear relationships. Linear programming is a specific case of mathematical programming.

More formally, linear programming is a technique for the optimisation of a linear objective function, subject to linear equality and linear inequality constraints. Its feasible region is a convex polyhedron, which is a set defined as the intersection of finitely many half spaces, each of which is defined by a linear inequality. A linear programming algorithm finds a point in the polyhedron where this function has the smallest (or largest) value if such point exists.

Linear programs are problems that can be expressed in the form:

$$\begin{aligned} &\text{maximize} && \mathbf{c}^{\mathrm{T}}\mathbf{x} \\ &\text{subject to} && A\mathbf{x} \leq \mathbf{b} \\ &\text{and} && \mathbf{x} \geq \mathbf{0} \end{aligned}$$

Where x represents the vector of variables (to be determined), c and b are vectors of (known) coefficients and *A* is a (known) matrix of coefficients. The expression to be maximised or minimised is called the objective function ($c^T x$ in this case). The equations $Ax \leq b$are the constraints subject to which the objective function is to be optimised. There are normally many hundreds or thousands of such equations. It has proved a useful tool in modelling diverse types of problems in planning, scheduling, design, etc.

Refinery linear programming models or LP models of all the oil companies were used to determine the hydrocarbon value of bio-ethanol in various petrol blends. Refinery LP models are licensed mathematical tools especially designed for each unique refinery configuration. They are able to represent the complexities of multiple refinery processes like distillation, conversion, purification and blending of products, and are able to perform calculations with a high level of accuracy and speed.

The effect on each refinery's gross annual margin when it is forced to blend bio-ethanol in 2%; 5% and 10% dilution into manufactured petrol was determined by first establishing a base case in which zero bio-ethanol is blended into petrol and by then running several LP model cases in which various dilutions of bio-ethanol are blended into petrol. Interpretation of LP model outcomes and the varying gross refinery margins allowed the bio-ethanol hydrocarbon value to be calculated. The cases for fuel specification waivers and other sensitivity analyses were similarly tested.

5. Capital and Operating Expenditure

The technical information was used to construct generic designs of a blending facility at either depot or refinery level, which met or exceeded the scope proposed by the oil companies. The designs were then independently verified and capital cost estimates generated by a third-party engineering company.

Three investment scenarios were compiled, namely a low-cost, high-cost and most likely-cost to the industry. The results formed the basis of the capital and operating cost elements of the financial model.

6. Financial Modelling

An Excel spreadsheet-based economic model incorporating the results of the LP modelling and refinery/depot expenditure analysis has been constructed. A scenario-based approach to the economic modelling has been taken to allow for permutations of low, high and most likely capital costs and bio-ethanol blend dilutions of 2%; 5% and 10% in petrol.

7. Capital Investment at Depots and Refineries

The depot blending design is based on receiving and blending ethanol in two grades of petrol/blendstock for oxygenate blending (BOB) either in existing petrol tanks or by side-stream gantry blending at the load rack. The blending is assumed to occur at a large depot with an annual petrol throughput of 500,000 m^3, implying an annual ethanol volume of 50,000 m^3 at 10% blending.

The refinery blending design is similar to the depot blending design for in-tank blending, except that the ethanol tanks and pumps are larger.

The designs were used to calculate a very rough order of magnitude (VROOM) estimate of the cost of the facilities. The cost estimations were outsourced to a third-party engineering company, Basil Read Oil & Gas, who have extensive experience in similar engineering work.
The direct costs for depot blending are an average of the direct blending and side-stream gantry blending designs. Allowance was made for larger ethanol tanks and reduced pipeline diameter for the depots designs in the direct costs. The indirect costs include bulk earthworks, civil works, electrical works, structures, mechanical installation, quality assurance and control, procurement costs and other indirect costs.

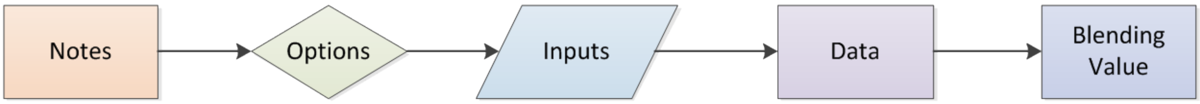
Three scenarios were constructed in order to estimate of the total cost of investment in South Africa to allow ethanol blending up to 10% by volume. They may be termed as low-cost, high-cost and most-likely scenarios, and are described below:

Scenario	Description
Low cost – Refinery blending	All ethanol blending occurs at the 6 refineries in South Africa in order to minimise the investment in the industry.
High cost – Depot blending	All ethanol blending occurs at depot level. If blending were to be carried out at every depot in the country the cost would be very high, so blending investment is limited to 2 large depots for each of the 7 oil companies
Most likely – a mixture of refinery and depot blending	Following the indicated preferences of the oil companies, it is assumed that 2 companies will blend at refinery and the remainder will blend at depots (2 each)

The generic designs for the depot and refinery modifications are representative of the requirements for bio-ethanol blending

8. Economic Model to Calculate the Bio-Ethanol Blending

The structure of the Excel spreadsheet-based economic model to calculate the ethanol blending value is depicted below. Each sheet is discussed in the next section.



The Blending Value should be used in the following equation to derive the delivered bioethanol price:

*Delivered Price = ULP95 BFP + Fuel Tax Rebates + Zone Differential + VAT + **Blending Value***

where the Blending Value may be positive or negative.