ETHANOL AUSTRALIA'S OCTANE ENHANCER

IMPLEMENTATION OF THE AROMATICS POOL REDUCTION IN AUSTRALIA'S FUEL STANDARDS

BIOENERGY AUSTRALIA
FUEL | GAS | HEAT | POWER

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TfA Project Group: Multi disciplinary design and engineering consultancy with 25 years' experience in downstream petroleum and biofuels projects.

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EXECUTIVE SUMMARY

Aromatics are one of the major components of gasoline due to their high octane rating. However, they also increase particulate matter and generate emissions that have negative effects on human health and the environment. Benzene in particular is classified as a carcinogen. Concerns have led to a worldwide reduction in aromatics over the last two decades.

In March 2019, the Fuel Quality Standards (Petrol) Determination 2019 was released with a 7% reduction in the permitted aromatic content from 42% to 35% v/v maximum pool average across all grades to be effective on 1 January 2022. This aligns Australia with European standards which lowered the permitted aromatic pool average to 35% in 2005.

Reducing aromatics subsequently requires additional components that provide a similar octane boost to maintain the fuel octane rating. In this regard ethanol is the most popular octane enhancer used worldwide to increase the octane of petroleum blend stocks. E10 blends are accepted globally for use in post 1986 passenger vehicles with world fuel ethanol consumption exceeding 100 billion litres. All petrol in the USA has an average of 10% ethanol equating to 600 billion litres per annum of E10, 30 times Australia's total petrol consumption.

Premium high octane fuels tend to have higher aromatics levels than regular unleaded petrol to achieve higher octane numbers with AIP data from 2014-2016 indicating regular unleaded had the lowest aromatic level at 25% and premium 98 the highest at 37% across the four Australian refineries.

Whilst this historical AIP data has been used for a minimum base case scenario, there are a number of independent fuel distributors who are not members of AIP and notably over one third of Australian petrol is currently imported. Australia's diminishing crude oil supplies and the closure of a number of refineries has resulted in Australia now importing 90% of our total petroleum requirements. As a result the composition of our fuel is likely to vary substantially subject to where we source our crude oil from, and the specific finished fuel composition imported from various international refineries. Subsequently three scenarios have been modelled to account for the uncertainty in the current and future aromatic composition of Australian fuels and potentially what is permitted to be sold under the new legislation compared to previous limits.

1. Potential 7% reduction in aromatics for premium 95 and 98 only
2. Base scenario with a 2% reduction in aromatics for premium 98 only.
3. Middle ground scenario with a 4% reduction in aromatics for premium 95 and 98 only

For the range of scenarios, it is estimated that an additional 113-550 ML per annum of ethanol production capacity would be sufficient to achieve the legislated aromatics reductions.

Whilst Australia currently has three ethanol plants with a capacity of 436ML per annum, ethanol demand is currently driven by a 4% ethanol mandate in Queensland and a 6% ethanol mandate in NSW. Under the mandate's ethanol is blended with regular unleaded petrol and sold as E10 (94 RON) as an alternative to regular unleaded petrol. Whilst the mandate targets are not currently being achieved, 607 ML of ethanol is potentially required to meet both mandates requiring an additional 170ML per annum of production. Considering recent announcements by the NSW government to renew their mandate and increase efforts for compliance, existing production has not been considered as being available for aromatic reductions in premium fuels.

The blending of ethanol with premium unleaded fuels would also allow modern vehicles which operate on 95 octane fuel or above to utilise the benefits of ethanol-blended fuel. Importantly this additional ethanol production could be achieved by utilising some of our agricultural exports without any additional land use or

Potential estimated benefits…Up to 3,990 new jobs could be generated, including 960 direct regional jobs.

impact on our food chain.

Reduction of aromatics levels using ethanol can generate significant potential economic and political benefits which are summarised in Table 1. Potential estimated benefits include:

- Up to six new plants of 100ML per annum production.
- Up to 3,990 new jobs could be generated, including 960 direct regional jobs.
- Up to $720 million in new capital investment and $500 million in yearly revenues.
- Greenhouse gas reductions up to 0.8 million tonnes CO2 equivalent.
- Sustainable, renewable Australian ethanol production supplying up to 6% of our petrol needs, improving fuel security whilst creating value added products.

Table 1: Scenario Summary

		Scenario 1	Scenario 2	Scenario 3
		Legislated 7% reduction (7% Premium 95 / 98)	**Minimum Base Case (2% PULP98)**	**Middle-ground (4% Premium 95 / 98)**
	Additional plants (100ML pa)	6	1	3
	Capital Investment	$720 million	$120 million	$360 million
	Yearly Revenue	$510 million	$85 million	$255 million
Jobs	Direct Jobs (Regional)	960	160	480
	Indirect Jobs (Broader economy)	3030	505	1515
	Total Jobs	3990	665	1995
	Australian fuel demand covered by ethanol (fuel security)	6%	3%	4%
	CO_2eq emissions reduction (million tonnes)	0.8	0.2	0.5

Australia is well-positioned to achieve the legislated aromatic reductions using ethanol which will have broad environmental benefits, generate new jobs and regional investment, reduce greenhouse gases, and improve fuel security.

GLOSSARY

Anti-Knock Index (AKI)

The anti-knock index Is the mean or average of the RON and the MON and often marked on the pump nameplate (R+M)/2. This is also known as the road octane number.

Fuel Sensitivity

The difference between RON and MON is known as the fuel's sensitivity and is not typically published for those countries that use the Anti-Knock Index labelling system.

Motor Octane Number (MON)

The other major test method to measure octane rating is Motor Octane Number (MON). This method uses a 900 rpm engine speed instead of the 600 rpm for RON. MON testing uses a similar test engine to that used in RON testing, but with a preheated fuel mixture, higher engine speed, and variable ignition timing to further stress the fuel's knock resistance.

Observed Road Octane Number (RdON)

This is derived from testing gasolines in real world multi-cylinder engines, normally at maximum throttle.

Octane Index

The term Octane Index is often used to refer to the calculated octane quality as opposed to the (measured) research or motor octane numbers. The octane index can be of great value in the blending of gasoline. The ability to predict the octane quality of the blends prior to blending is essential, something for which the calculated octane index is especially suited.

Octane Rating, or octane number

A standard measure of the performance of petrol in an engine. The higher the octane number, the more compression the fuel can withstand before detonating.

PULP95

Premium unleaded petrol with a 95 octane rating and minimum MON of 85.

PULP98

Premium unleaded petrol with a 98 octane rating and minimum MON of 85.

Research Octane Number (RON)

The most common test method to measure octane rating worldwide is the Research Octane Number (RON). RON is determined by running the fuel in a test engine with a variable compression ratio under controlled conditions and comparing the results with those for mixtures of iso-octane and n-heptane.

RULP

Regular unleaded petrol with a 91 octane and minimum MON of 81.

INTRODUCTION

The composition of Australian fuel directly affects the quantity and type of vehicle emissions. Ultimately, this is impacting the quality of the air and the amount of greenhouse gas in the environment. The drive to improve Australia's fuel standards provides benefits from a vehicle efficiency and overall emission control system standpoint.

In a drive to reduce the impacts of noxious vehicle emissions, Australia has historically adopted increasingly stringent European vehicle emission standards. Local fuel parameters are specified in standards for each type of fuel, made as legislative instruments under the Fuel Quality Standards Act 2000 (the Act). These parameters set the physical properties and permitted chemical composition necessary for the fuel to be used in engines. One of the major petrol parameters is aromatic content.

Aromatics are noted for their high octane rating; however, they can form combustion chamber deposits in engines, increase particulate matter and generate emissions that have negative effects on human health and the environment. Benzene in particular is classified as a carcinogen, especially when only partially combusted. Concerns have led to a worldwide reduction in aromatics present in blends over the last two decades. Currently, the Australian permitted aromatic content is 45% by volume, with a pool average across all grades of 42%. This lags behind the current European fuel standards of 35% which were established in 2005.

In March 2019, the Fuel Quality Standards (Petrol) Determination 2019 was released with a reduction in the permitted aromatic content from 42% to 35% v/v maximum pool average across all grades to be effective on 1 January 2022.

The reduction in aromatics will require additional components that provide a similar octane boost to maintain the fuel octane rating. Ethanol is widely recognised as a proven octane enhancer and is the most popular octane booster used worldwide to increase the octane of petroleum blend stocks.

This report aims to establish the benefits of using ethanol as Australia's Octane Enhancer. Further, this report will review key considerations inherent to the proposed strategy for the implementation of aromatics pool reduction in Australia's fuel standards.

HISTORY OF OCTANE IN PETROL

Octane – What is it?

A fuel's octane number is a vital measure of how much compression it can withstand before automatically combusting in the cylinder of a petrol engine. Spark-ignition petrol engines compress an air-fuel mixture and ignite it with a spark plug momentarily to achieve the maximum combustion and energy extraction. Pre-ignition can occur when the unburned air/fuel mixture is compressed quickly and detonates. As such, it is vital that high compression ratio engines use high octane fuels so as to avoid pre-ignition, also known as knocking. When knocking occurs it leads to poor performance, a metallic ringing noise and engine damage through pressure waves blasting the piston and other engine parts [27]. The fuel's propensity for pre-ignition is described by two main octane numbers, RON and MON.

Figure 1: Fuel pumps in USA with AKI (Left) [20] vs. Australian Fuel pumps with RON (Right) [42]

Fuels with a large difference in RON and MON are more unpredictable and have a higher fuel sensitivity (RON – MON). Adding a substance with a high octane number to a low-octane mixture will generally result in an increase in overall octane. These high octane substances are known as octane boosters or enhancers and will typically have an individual RON of greater than 100. Octane enhancers are usually oxygen dense compounds such as ethers, olefins, and alcohols. Having more oxygen in the air/fuel combustion mixture is beneficial because it facilitates a greater degree of combustion and reduces unwanted incomplete combustion pollutants. Most modern-day drivers will not experience engine knocking because fuels contain an oxygenate that prevents knock by adding oxygen to the fuel and increasing octane. This increases engine efficiency and thus prevents damage to newer high compression cars [2].

Petrol Components and Octane Rating

Typical Petrol Components

Petrol is a refined product of crude oil which usually contains a mixture of hydrocarbons, additives and blending agents. The composition can vary substantially depending on the source of the oil, the refinery process and the product specifications. Additives and blending agents are used to improve the performance and stability of the petrol. The typical chemical hydrocarbon composition in gasoline is: 4-8% alkanes; 2-5% olefins; 25-40% isoalkanes; 3-7% cycloalkanes; 1-4% cycloalkenes; and 20-50% total aromatics (0.5-2.5% benzene) [64].

BTEX Aromatics

BTEX Aromatics are a high octane group of chemicals with similar properties that naturally occur in crude oil. A BTEX complex is typically a mixture of benzene, toluene, ethyl-benzene, and xylene. The BTEX aromatics are derived from the gasoline fraction of petroleum products and the catalytic reforming of naptha [32]. Notably, benzene usage in fuel has been linked to developmental disorders, cancers and cardio-pulmonary abnormalities. This has resulted in benzene being regulated to a maximum of 1.0% v/v under the Fuel Quality Standards (Petrol) Determination 2019 [22]. Toluene and xylene are both widely available and have excellent blending properties due their high RON, providing a good mechanism to raise the octane number. These are typically used in proportions from 20-40 v/v %. Legislation has since been introduced to reduce overall aromatic concentrations in fuels. Although not as toxic as benzene, low-level BTEX exposure has been linked to negative developmental, reproductive, and immunological responses [28].

	Research Octane Number (RON)	Motor Octane Number (MON)
Benzene	98	90
Toluene	124	112
Ethyl-Benzene	124	107
Mixed Xylenes	137	117

Table 2: Aromatic blending octane numbers - API ASTM Research Project 45 [37]

Olefins

Olefins are unsaturated hydrocarbons containing a double bond between two carbon atoms. Notably they have a significant octane impact having typical octane numbers above 150. Examples of Olefins are butylene (butene) and propylene (propene). In gasoline, the high RON value of olefins significantly boosts the octane rating. However, because they tend to form harmful deposits inside engines, limits are typically set for total olefin content. [43] Refinery streams containing high percentages of olefins, such as coker naphtha, have a tendency to polymerize and form gums that can negatively impact storage and transportation systems. As a means to negate these effects, the streams are usually hydrotreated to saturate the olefins. Some refineries produce olefins such as propylene which is a typical feedstock for petrochemical production. In a refinery, olefins are an important feedstock into the alkylation unit to produce alkylate (a high-value gasoline blend stock). The olefins most commonly used in the alkylation unit are butylene and propylene, which primarily come from the FCC unit.

Major Octane Enhancers

Tetra Ethyl Lead

Petrol (known as gasoline in the USA) has always needed additional octane to perform adequately in combustion engines. In 1921 automotive engineers working for General Motors discovered tetra ethyl lead was a much cheaper alternative to ethanol to boost the octane rating of gasoline [2]. Leaded gasoline dominated from then until it was phased out in the 1970s by the U.S. Environmental Protection Agency (EPA) because of the linked health impacts. Many Australian vehicles built before 1986 were designed to run on leaded fuel before it was finally banned completely in 2002. This marked the birth of unleaded petrol.

Ethers and MTBE

Methyl Tertiary-Butyl Ether (MTBE) was progressively adapted as an octane enhancer from 1979 onwards to replace tetra ethyl lead [28]. It was popular in reformulated gasoline which required increased oxygenate content and was mandatory in areas in the U.S. which did not meet ground-level ozone standards. In 1999 a U.S. EPA Blue Ribbon Panel investigated health concerns related to MTBE solubility in groundwater. It found that conventional gasoline floated on the groundwater, but the MTBE component was absorbed into the groundwater causing permanent contamination. To protect drinking water MTBE was phased out of Australian mainstream usage by the Federal Environment Minister in 2004 by limiting MTBE levels in petrol sold in Australia to 1% v/v.

Ethanol

Pure ethanol has a RON of 109 and was one of the first automotive fuels used to fuel the Model T Ford in 1908 [2]. Ethanol burns cleanly, lowers emissions, and improves the efficiency of combustion by providing additional oxygen. Subsequently it is known as both an octane enhancer and oxygenate. More stringent regulation of air and water pollutants has resulted in renewed interest in ethanol as a renewable fuel. Today, most petrol in the United States is blended with ethanol to produce E10 (10% ethanol, 90% petrol). Over 95% of gasoline sold in the United States is E10 [2].

Octane index

The gasoline industry ranks substances in an index to predict the octane quality of blends. Substances can be ranked according to pure component octane or blending octane. Pure component octane is the anti-knock performance (RON/MON/AKI) of an individual, pure component by itself. Blending octane is more relevant for refinery operators as it is the anti-knock performance of a blending compound when it is a component of a gasoline blend. This is typically harder to measure as it can differ depending on the specific petroleum chemistry. Specifications are normally given as a probable range of blending octane number. Average values for blending octane number AKI of a range of octane enhancers is presented in Figure 2 [20] which shows ethanol has a distinct advantage when compared to many other octane enhancers. The only substance with a higher average blending octane number is methanol, which is not approved for use in fuels due to its toxicity in water supplies.

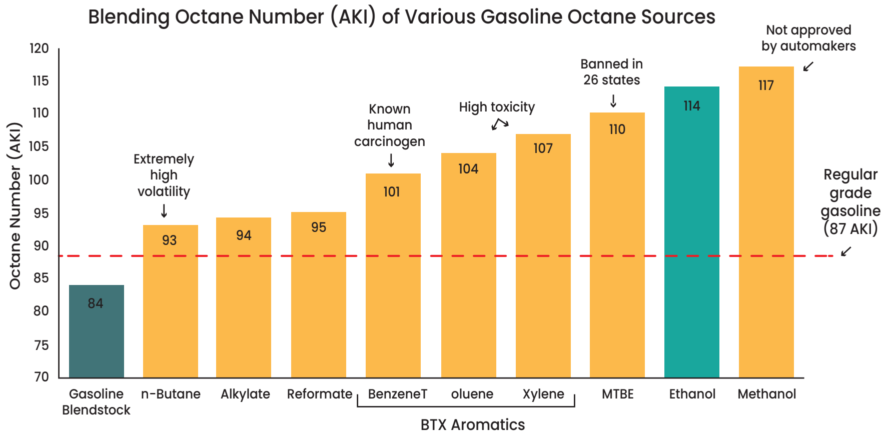


Figure 2: AKI of various Gasoline Octane Sources as per the RFA and MathPro Inc. [20]

ETHANOL AS AN OCTANE ENHANCER

Ethanol has historically had many uses, including industrial solvents, alcoholic beverages, medical sterilising agents as well as long term use in transport fuels. Most ethanol is produced by the fermentation of sugars sourced from sugarcane, starch or cellulose in a low-emissions process based on the principle that the plant life used as feed absorbs the carbon dioxide from the atmosphere in a short-term cycle. This is referred to as circular economy recycling of carbon in the atmosphere. Ultimately, this renders ethanol a renewable fuel.

Overview of ethanol usage in fuels

Ethanol is predominantly blended into fuel as E10 worldwide with varying levels of market penetration. In Australia. E10 is a blend of 91 RON regular unleaded petrol (ULP) with up to 10% ethanol. This increases the RON from 91 to 94.7 [13], which is typically just under the specification for 95 RON premium unleaded petrol (PULP). Australian Ethanol-blended fuel accounts for 14% of total automotive gasoline sales [11]. In contrast almost all USA motorists use E10. [2]

Worldwide, ethanol has experienced significant growth as a fuel due to major mandates in the EU, US, China and Brazil. Notably, well over 60 countries have adopted biofuels mandates. [47] These have been driven by the multiple benefits ethanol provides as a transportation fuel, including improved air quality, reduced greenhouse gas emissions [23], economic stimulus to domestic agriculture and rural areas and fuel security. The magnitude of the environmental impact of ethanol varies depending on the feedstock and production process employed. The production of ethanol is also energy efficient generating 1.6-4.6 times more energy than the fossil energy used to produce it (subject to the feedstock used) [38].

First generation technology ferments sugars from sugarcane and grain starch to make ethanol. This technology is considered mature and achieves significant greenhouse reductions in the order of 39 - 43% (using corn) to 51% (using sugar cane) [38]. Current trends and potential actions by refineries could improve the GHG profile of corn to 47-70% relative to gasoline [81]

Second generation technology known as advanced biofuels focuses on biomass as a feedstock. Lignocellulosic conversion breaks down agricultural waste and wood residues into sugars which can then be fermented. Importantly, this technology facilitates increased production without any additional land use and generates larger greenhouse gas emissions reductions in the order of 90% [38].

Early plants built using second-generation technology (circa 2010) struggled to achieve reliable performance however significant optimisation strategies have been employed to improve the technology. Since then, a new generation of commercial scale lignocellulosic plants are currently under construction in Romania, India and Finland. Clariant's

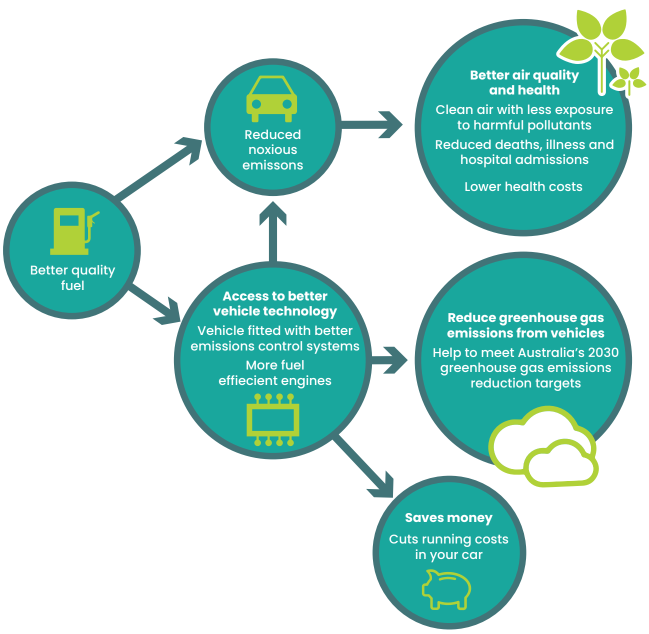


Figure 3: The benefits of better quality fuel [13]

Romanian plant is earmarked to be commissioned in 2021-2022 to produce 50,000 tonnes of cellulosic ethanol per year [16]. Praj Industries operates successful pilot and demo plants in India manufacturing 1 million litres of ethanol per annum and is licensing its Enfinity technology for use in 2G USA and Brazilian plants. [65,66] Finnish Chempolis is contracted in India to utilise their Formico technology to produce ethanol from bamboo [67].

Third generation technology includes a variety of technologies including gasification of municipal solid waste (MSW) and wood residues with gas fermentation processing. This technology is considered the final frontier to work towards a circular economy however it still ranks low in terms of its techno-commercial readiness. The first plant using this technology with steel mill emissions opened in 2018 in China.

Ethanol uptake has significantly increased in recent years, especially in the United States. Ethanol was added to US gasoline in the 1980s and 1990s at similar concentrations as today (10% v/v, E10) but now at a much larger scale.

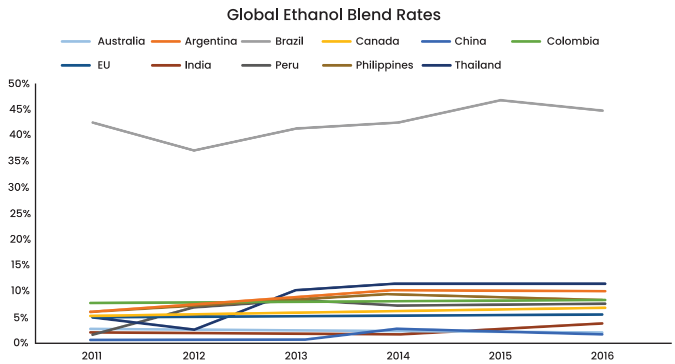


Figure 4: Global Ethanol Blend Rates - Image source: [39]

Ethanol is now the leading octane enhancer worldwide, claiming 71% of a 112 Million Metric Tonne (MT) market share as at 2016 [39]. The average blend rate of ethanol with gasoline is 10% domestically in the US and between 5% and 8% globally [39]. The 25% ethanol mandate in Brazil and the rapid adoption and commercial success of "flex" vehicles presents Brazil as an emerging leader in overall ethanol to gasoline implementation.

The energy content of ethanol is about 30% less than gasoline on a volume basis, however this is offset to a degree by ethanol acting as an oxygenate to achieve more complete fuel combustion and efficiency of engine operation.

Ethanol's impact on octane number

The RON and AKI of pure ethanol are approximately 109 and 99 respectively, which is higher than the octane of premium Australian gasoline (95 and 98). Notably the blending RON and AKI are higher when ethanol is used as a blend component. Figure 5 shows modelling of ethanol blended with differing gasoline blend stocks with various octane numbers. Ethanol's blending octane number increases with lower-octane hydrocarbon blend stocks.

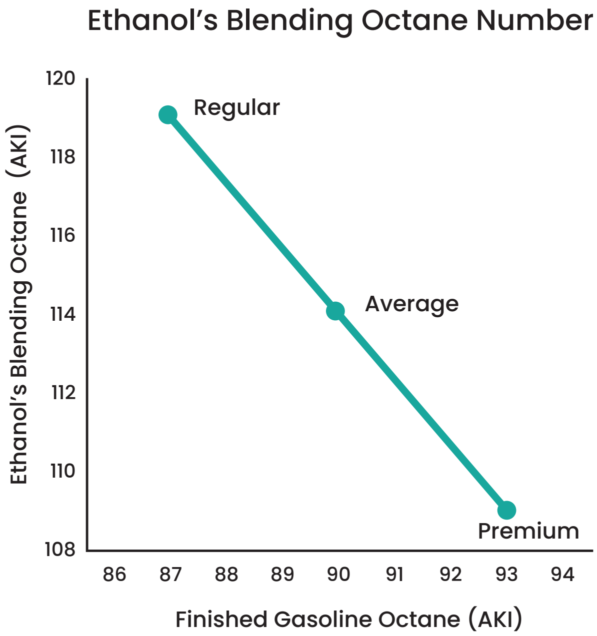
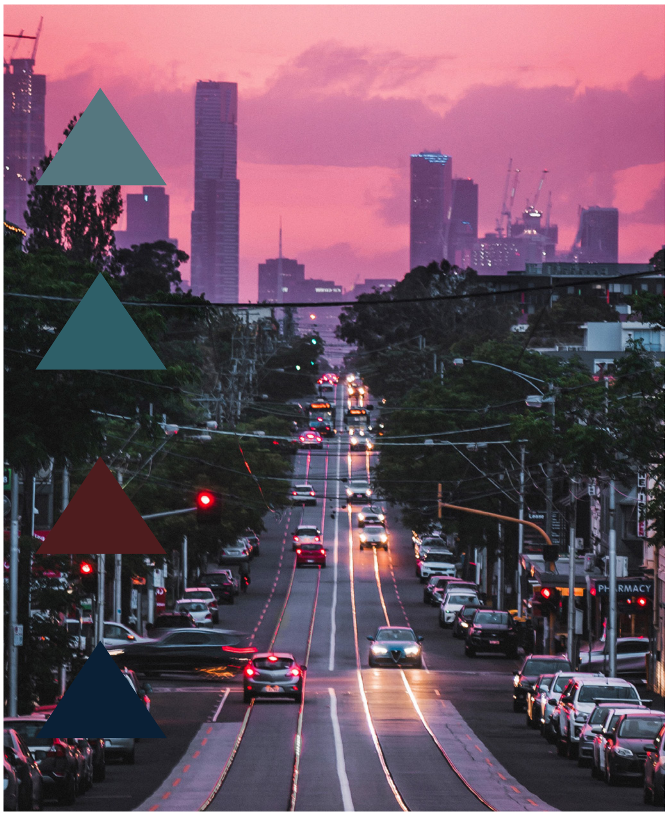


Figure 5: Ethanol's blending octane number [20] - RFA (MathPro Inc.)



THE GLOBAL TREND TO REDUCE AROMATICS

Australia is one of the few major economies in the world yet to strictly address transport emissions. In the last 20 years worldwide ethanol production has increased by a factor of five. Overall, capacity is now well over 100 billion litres, mostly using first generation technology [54]. International experience, specifically from America, has shown that aromatics reductions can be achieved by blending with ethanol.

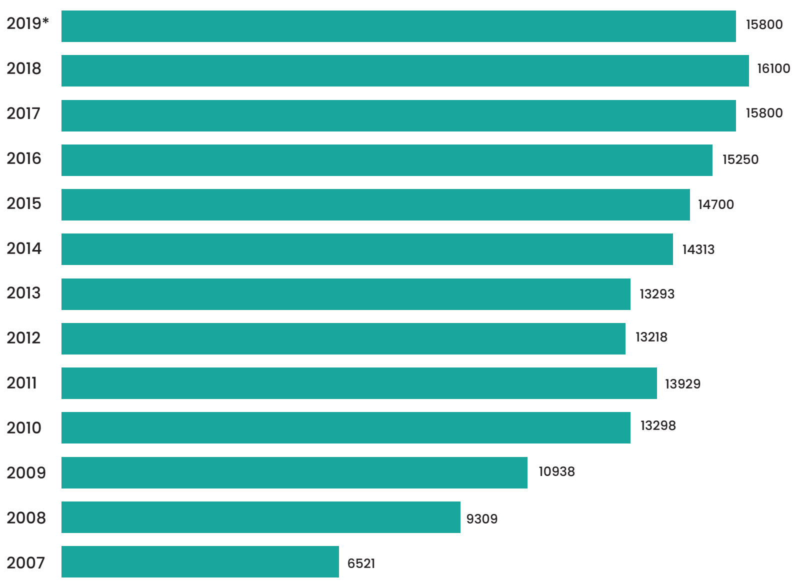


Figure 6: Statista USA Ethanol Production in millions of US Gallons [79]

United States of America

America's growth in ethanol has been driven by oxygenate legislature and its role as an octane enhancer. Predominant drivers behind this change have been driven by environmental and health effects supported by the Renewable Fuels Standard which began to have major market impact in 2007. Refer to Figure 6.

The air quality and ethanol in Gasoline report by Gary Z. Whitten, states "since both ethanol and aromatics add octane, it can be expected that using ethanol in place of aromatics for octane would reduce primary PM2.5 emissions (fine hazardous particles) even more than had been seen in Colorado (1999) study [5]."

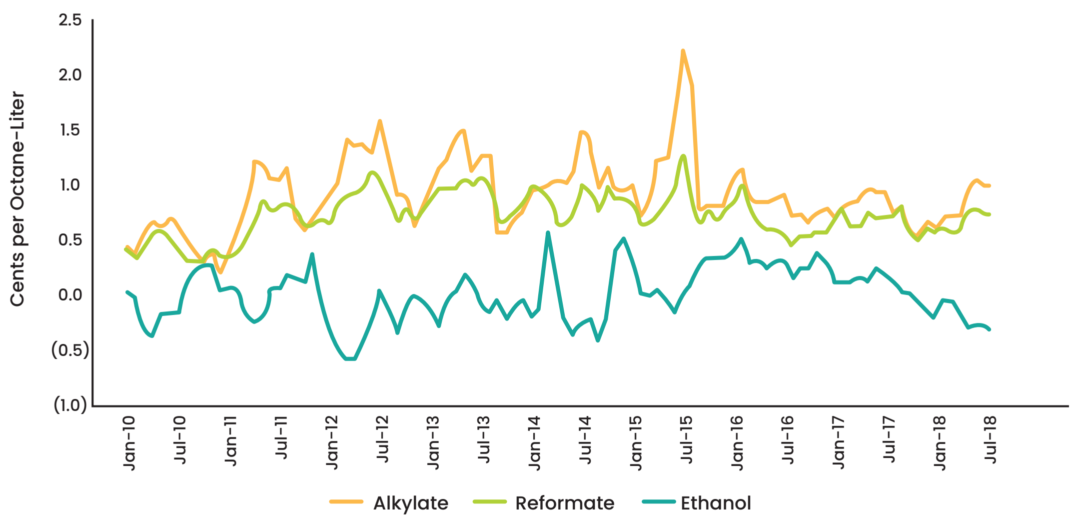


Figure 7: Ethanol as a cheaper source of octane – [39]

The direct impact of ethanol in reducing the levels of aromatics and olefins in American gasoline is illustrated in Figure 8.

Additional legislation passed by Congress, the Energy Independence and Security Act (EISA), significantly increased the volume of renewable fuels mandated under the RFS to 36 billion gallons by 2022 [2].

The United States has also derived economic benefit from investing in ethanol as a blend stock for Oxygenate Blending (BOB). The use of BOB has resulted in cheaper, less intense

Although Australia lags behind when compared to the progress made in Europe, the implementation of the 2022 legislation to reduce fuel aromatics from 42% to 35% will drive the change required for the implementation of ethanol [13]..

reformation of the oil which has saved refineries on energy costs and allowed them to make use of lower octane components which would have otherwise needed to be discarded.

Blending in ethanol downstream at 10% v/v has allowed refineries to achieve 4 RON points octane uplift, 3.5% oxygen and 0% incremental sulphur additions. This has been a contributing factor to ethanol being a low cost source of octane. Since 2010 ethanol has been cheaper than either alkylate or reformate by over 0.7 cents per octane litre as shown in Figure 7. An octane litre is a litre of substance which is primarily added as octane enhancer.

Europe

European Fuel Standards are regarded as international best practice. Since 1992 the EU has introduced increasingly stricter limits through a series of 'Euro' standards. Europe has displayed a similar trend of reduction in aromatics; however, they still allow components such as Ethers (e.g. MTBE used). They have an ongoing strategy of ethanol implementation as part of efforts to make their fuel more environmentally friendly. Most petrol sold is at least E5, while some European nations have also progressed to E10. [44]

While Australia's car manufacturing standards are at Euro 5 standard, and looking to move to Euro 6, Australia's fuel standard lags behind at Euro 2-3. In 2005 Euro standard 4 came into force with EU Directive 98/70/EC which mandated a maximum aromatics volume percentage of 35% as compared to the maximum Euro standard 3 of 42% (pre-2005).

Although Australia lags behind when compared to the progress made in Europe, the implementation of the 2022 legislation to reduce fuel aromatics from 42% to 35% will drive the change required for the implementation of ethanol [13].

LEGISLATION (IN THE AUSTRALIAN CONTEXT)

The Better Fuels report of August 2018 [13] recommendations were implemented via legislation provisions under the Fuel Quality Standards Act 2000 section 21. This was instrumental for the development of the Fuel Quality Standards (Petrol) Determination 2019 released on 18 March 2019 by the Minister for the Environment.

The following are a summary of major changes as presented in the Better Fuels Explanatory Statement 2019 [12].

Aromatics

The maximum pool average is reduced from 42% v/v to 35% v/v commencing 1 January 2022. Pool average refers to the average amount of aromatics in all batches of a supplier's petrol of each grade (RON 91, 95 and 98) over a period of 12 months starting 1 January. This reduction has the capability to significantly reduce the octane of petrol and needs to be substituted by an equivalent octane enhancer. The change reflects the aromatics maximum reduction which was first legislated in Euro 4 Standards implemented in Europe in 2005 and which has been maintained through to Euro 6c and 6d ratings. Australia has committed to reducing the pool average but not the aromatics limit. There is, however, a commitment to review the aromatics limit in petrol by 2022 to set a reduced limit by 2027 or establish an alternative solution [13].

Importance of aligning to Euro Standards

In Europe, the European Standard EN 228 places a limit on the aromatics content to a maximum of 35 % v/v which is required to be met for Euro 6c and Euro 6d rating. The majority of vehicles being produced in Japan and Europe will have engines of this specification up to 2030. It is critical for fuel used in these cars to be optimised in an effort to reduce risks to advanced engine and emissions systems. The Better Fuels RIS in particular states the following advice from ABMARC [13]:

"Independent analysis undertaken for the Department identified that the risk in maintaining the current 45 per cent aromatics limit is that Euro 6c, and in particular Euro 6d (due to the significantly lower particle number limit) petrol cars that are fitted with particulate filters may have a higher rate of in-service problems in Australia compared to Europe.

Principally, these problems are expected to be:

- blocked particulate filters due to increased particle production.
- higher than normal fuel consumption and possibly reduced drivability or throttle response due to increased deposits fouling fuel injectors."

USING ETHANOL TO ACHIEVE AROMATIC REDUCTIONS

This section will evaluate the amount of ethanol required to replace the lost octane and compare this with worldwide experience within the global trend of using ethanol to replace aromatics.

Theoretical Replacement of Octane Boost

Modelling by the government and AIP to date [13] has assumed large increases in refinery upgrade costs and operating costs to achieve the sulphur and aromatics reductions required. However, international experience has shown the increase in RON can be achieved through the blending of ethanol with existing refinery products, avoiding significant refinery modifications and simultaneously reducing aromatics and sulphur. When estimating the potential ethanol volume required to achieve legislative requirements, a conservative approach was adopted. Modelling assumes that premium unleaded petrol aromatics pool averages are at the maximum permitted amount currently and require 7% aromatic reduction from 42% to 35% as per the government mandate.

Several references [1], [26], [34], [35] have demonstrated that the octane rating of a blend can be predicted based on the individual octane numbers of the components and their molar composition (X%)

$$RON_{blend} = x_A \times RON_A + x_B \times RON_B + x_C \times RON_C + x_D \times RON_D \quad eqn\ 1$$

On a molar concentration basis ethanol has an advantage in providing an equivalent octane boost as it is a much smaller molecule than most BTEX aromatics with a molecular weight of 46g/mol versus ~100g/mol. Considering typical density values, there are nearly twice as many moles of ethanol per unit volume than aromatics. Importantly, the weighting of the octane rating of the individual components must also be taken into consideration. Octane numbers used in the calculations are shown in Table 2 and Figure 5. Given the blending octane numbers of net aromatics in any refinery stream can vary day to day, the values in Table 2 above were taken as representative for the purposes of this investigation. Indicative gasoline aromatic compositions were used from [7] for each component to calculate a collective RON and MON for blended aromatics.

Whilst the analysis was specific to the reference analysis [7], it is notable that the octane reduction due to reducing aromatics in RON 91, 95 and 98 petrol can be replaced with approximately 60-70 % of the same volume of ethanol as the aromatics being offset. This is not a final solution though, as we now have less total volume than we started with and a make-up quantity is required to off-set the difference to maintain the 35% aromatics composition.

Economically, the cheapest replacement would be lower octane components rather than octane enhancers. However, this will further reduce the octane and will result in more ethanol being required to achieve the legislative RON and MON requirements of each petrol grade. Notably more ethanol is required to increase the octane of higher octane components than lower octane. Figure 5 shows the decrease in ethanol's octane blending power as the finished gasoline octane increases.

For purposes of modelling, when considering the decreases in octane due to removal of aromatics, it is important to note the refinery compositions of aromatics and BTEX vary with every batch. Whilst representative batches of aromatics using set fractions of BTEX for each octane group were used to perform calculations, aromatic blending octane numbers are highly dependent on the composition of the base gasoline and on the percentage blended. Aromatics typically have strong deviations from linearity when blending, and the blending differential varies greatly from compound to compound. Notably the calculations reflect only the particular batch composition scenario being modelled and would require further refining for broad application. In summary, the calculation result cannot simply be used with certainty for the amount of ethanol required to be added to all fuel blends. However, it can be stated that:

Theoretically in comparison to aromatics a lower volume of ethanol is required to meet the same octane requirements in 91, 95 and 98 unleaded petrol.

Global experience of aromatic reductions with ethanol

Ethanol has been blended in petrol in America in substantial quantities for over 20 years. Whilst legislative drivers have been based on an oxygenate mandate, the octane enhancing properties have resulted in significant reductions of other high octane components such as aromatics and olefins.

Figure 8 shows US EPA data for US gasoline over a 10 year period. In 2006, average US gasoline contained 24.7% aromatics, 11.1% olefins, and 2.91% ethanol. In 2016 ethanol increased by 6.66% in volume with a 5.4% reduction of aromatics and a 2.5% reduction in Olefins. Figure 8 may also represent the effect of other driving factors, such as increased demand for heavy components for diesel blending, changes in exports and premium fuel demand, and the sympathetic reduction of sulphur, benzene, MTBE and olefins in gasoline. Overall, the 2006-2016 historic trends show a combined reduction in volume of aromatics and olefins of 7.9% for a 6.66% addition of ethanol. E10 is now the national normal for the US, with all gasoline having 10% ethanol on average.

Figure 9 summarises indicative US blends provided by the Automobile Alliance and EPA and the impact of ethanol addition whilst maintaining similar octane levels. This shows that the transition to E10 has resulted in an average reduction of aromatics by volume from 32% to 22%. This is equivalent to a 1:1 substitution ratio.

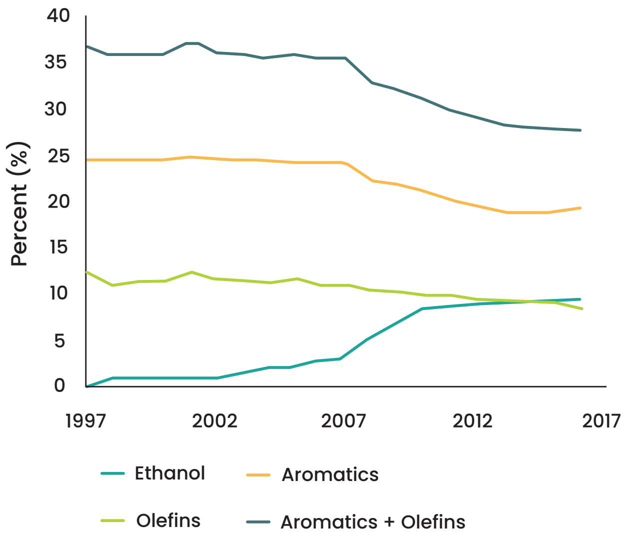


Figure 8: Changes in composition of gasoline during Ethanol introduction USA EPA [28]

Many US refineries blend lower octane petrol blends to take into account the octane boost from adding ethanol. This represents a major shift in thinking for Australian refineries that have typically held final petrol blends in batches at the refinery to meet expected demand. Notably, this does not imply that major capital upgrades are necessarily required by refineries. In contrast, since the reformer stress is lessened by lower aromatics requirement the substitution could result in a significant decrease in refinery operating cost. The blending of ethanol being cheaper than reforming is a key driver of ethanol growth from 2006-2016 in the United States which has resulted in a close to 1:1 replacement of aromatics with ethanol in the United States. Similar logic has been applied to Australian fuel to ascertain expected demand.

Representative summer regular AKI blend properties based on available Automobile Alliance fuel data and EPA fuel quality trends.

	E0	E10	E15
API	57.1	58.7	57.4
Vap. Press, psi (EPA)	8.2	8.2	7
Distillation, Deg. F			
10% evap.	136	129	129
20% evap.	161	138	138
30% evap.	191	146	148
40% evap.	207	156	156
50% evap.	219	192	162
60% evap.	234	224	208
70% evap.	251	249	247
80% evap.	283	279	279
90% evap.	325	320	320
Aromatics, V%	32	21.8	17.4
Olefins, V%	9	8.1	7.65
Saturate, V%	59	60.1	59.9
RON	92.1	92.2	92.4
MON	83.4	83.3	83.1
AKI	87.8	87.8	87.8

Figure 9: Reduction of Aromatics in USA with Ethanol [28]

How much Ethanol do we need?

The theoretical amount of ethanol needed to replace aromatics calculated above was based on a particular blend composition [7] and hence needs to be considered in the context of real industry blending experience with ethanol addition and the replacement of aromatics with other blend components.

The calculation finding is supported by actual fuel trend data in Figure 8 where effective reductions in aromatic and olefin levels of 7.9% have been achieved with only a 6.66% increase in ethanol volume. This is particularly notable as olefins typically have significantly higher octane numbers than ethanol.

Taking into account global blend property statistics in Figure 8 and Figure 9, it is considered reasonable to infer the addition of ethanol appears to achieve at least a 1:1 reduction in the level of aromatics in real world blending trends. Hence based on existing research and real world data and for the purposes of this report, the potential addition of ethanol to achieve the legislative requirement to reduce average pool aromatics from 42% to 35% is considered to be on a 1:1 basis.

The addition of ethanol at 7% is considered to typically reduce aromatics content by an equivalent 7% in a petrol blend whilst maintaining octane rating.

Premium high octane fuels tend to have higher aromatics levels than regular unleaded to achieve higher octane numbers. AIP data from 2014-2016 is consistent with this premise indicating aromatic levels in Australian regular unleaded petrol were the lowest (25%) with premium 95 petrol (30%) and premium 98 (37%).

Whilst AIP historical data has been used for a minimum base case scenario, it is not representative of the entire industry. There are a number of major independent fuel distributors such as Puma Energy (recently acquired by Chevron), United Petroleum and On the Run who are not members of AIP and held 25% of the petrol market in 2017. In 2018/19 over one third of Australian petrol was imported [11]. Notably the recent announcement by BP to close the Kwinana refinery and ExxonMobil to close the Altona refinery will substantially decrease local production and increase imports further.

Australia's diminishing crude oil supplies and the closure of four Australian refineries over the last six years has resulted in Australia now importing 90% of our petroleum requirements. Hence the composition of our fuel is likely to vary substantially subject to where we source our crude oil from, and the specific finished fuel composition imported from various international refineries.

Subsequently it has been assumed that regular unleaded petrol, as the lowest octane fuel which needs the least octane boosting, will continue to be able to be produced in compliance with the new 35% aromatics limit. Whilst AIP historical data for premium 95 fuel was also below the future limit; it has been considered in the study due to its higher octane requirement and the potential variation in composition associated with importing 90% of our petroleum requirements into the Australian market.

Three scenarios have been modelled to account for the uncertainty in the current and future aromatic composition of Australian fuels and potentially what is permitted to be sold under the new legislation compared to previous limits.

1. Potential 7% reduction in aromatics for premium 95 and 98 only.
2. Base scenario with a 2% reduction in aromatics for premium 98 only.
3. Middle scenario with a 4% reduction in aromatics for premium 95 and 98 only.

This has been applied to Australian fuel sales numbers which come from the Australian Petroleum Statistics [11] Table 3A (FY18-19) to emulate normal production pre-Covid19 over a year.

(In ML)	Regular (<95 RON)	Premium (95-97 RON)	Premium (98+ RON)
Sales of Automotive Gasoline	9862.1	2195.4	3077.9
7% reduction in aromatics	-	153.7	215.5
Potential Ethanol Volume Required	-	153.7	215.5

Table 3: Potential maximum demand for Ethanol in Australia using 2018/19 data EPA

It is important to note that the composition of fuel sales is changing as the passenger fleet modernises and more cars are using premium fuels. Notably over the last eight years premium unleaded petrol (PULP) 98 sales have increased by 55%, premium unleaded petrol (PULP) has remained relatively constant and regular unleaded petrol (RULP) sales have fallen 13%. It has been assumed that premium 98 fuel sales will continue to increase over the next ten years, to offset the steady decrease in regular unleaded sales. This is an extension of the trends seen since 2011, assuming total fuel sales remain relatively constant, adjusting for an uptake of electric and hydrogen fuel cell vehicles as per [73]. Estimated demand is shown in Figure 10.

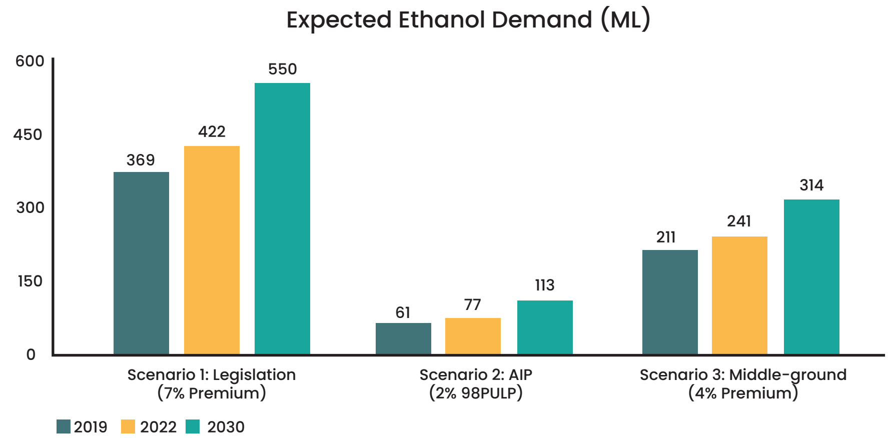


Figure 10: Expected ethanol demand (ML) under three scenarios [28]

It is also noted that Queensland and NSW have mandates in place of 4% and 6% respectively.

- In 2018/19 total RULP and E10 sales in Queensland were 2,677 ML. If the mandate were met ethanol supply would need to be 267 ML.
- In 2018/19 total petrol sales in NSW were 5,674 ML. If the mandate were met ethanol supply would need to be 340 ML.

These volumes are in addition to the above scenario estimates as they are predominantly marketed as an alternative to regular unleaded fuel and not premium unleaded fuels.

VEHICLE COMPATIBILITY

Ethanol has over a 100 year history as an automotive fuel. It burns cleaner and has a higher octane number than gasoline.

The model T Ford released in 1908 was designed to use pure ethanol as fuel [68].

Commercial scale ethanol production in Australian began in 1927 when CSR opened their distillery at Sarina. Now owned by Wilmar, the Sarina sugar mill and ethanol distillery still operates today. Notably the use of E10 ethanol fuels in Australia dates back to 1929.

From 1929 – 1957 all petrol sold in Queensland contained 10% ethanol [70].

Most Australian vehicles manufactured after 1986 are typically considered to be able to use ethanol-blended fuels up to E10. The Federal Chamber of Automotive Industries (FCAI) has a comprehensive list of those vehicles which it believes are too old to be able to operate with ethanol. The difference around this year is predominantly the popularity of carburettors which abounded before 1986. Carburettor systems may experience hot fuel handling concerns, meaning ignition issues caused by ethanol's high ability to vaporise. Ethanol also has an affinity for water which can be a problem in old fuel lines as they are more prone to rust. Water can also result in the engine hesitating and running roughly. [44]

NRMA and NSW

The NSW government ran an E10 fuel for thought education campaign in 2017 to encourage motorists to check their car for E10 compatibility. The NRMA stated in a supporting statement, "Despite many common myths and misconceptions, around 90 per cent of petrol cars can safely use E10." [45]. Today the NRMA website states:

"E10 is a safe and reliable fuel, compatible with the majority of petrol-powered cars on the road today." [41]

QLD Government

Similarly, in 2016, the Queensland government launched their E10 OK campaign seeking to encourage motorists to increase their use of biofuels. Commentary from the Minister for Energy and Biofuels Mark Bailey is as follows:

"The campaign's interactive E10 OK website has a vehicle E10 compatibility checker, which allows motorists to search by their vehicle's registration or make and model to check if it's E10 compatible. The biofuels campaign will focus on the benefits of the transition to this cleaner-burning fuel. It encourages motorists to take a fresh look at E10's high quality, more modern car technology and highlights that E10 use helps to advance Queensland's economy. By supporting the use of biofuels, we have an opportunity to drive jobs growth in regional Queensland and add value to the State's abundant agricultural resources." [47]

RACQ

RACQ state on their official website that "Most, but not all, petrol vehicles sold in Australia after 1986 can use E10." [48]

In 2016, now RACQ Chief Communications Officer Paul Turner stated,

"Unfortunately for nearly a decade we've been told it's bad for our cars and that it has terrible qualities. The fact is that 85 per cent of petrol cars on our roads in Queensland can use E10 safely and efficiently. 10 years ago, when E10 was first introduced, many cars could not handle the biofuel, which gave it a bad reputation. However, many of the cars we drive now aren't built in Australia but in Asia or Europe. In those countries they have a large ethanol usage." [49]

USA

The USA has over 20 years real world experience with ethanol E10 blended fuels. As per Figure 6, the USA used nearly 60 billion litres of ethanol per annum in 2019.

Given all petrol in the USA typically has 10% ethanol on average, annual E10 usage in the USA is 600 billion litres per annum, 30 times the amount of petrol used in Australia.

Europe

Europe has been steadily increasing the ethanol usage in European vehicles. The majority of EU member states currently use at least Premium E5 petrol in their vehicles, with the majority using an average mix from 5-10%. In January 2020, Denmark, Hungary, Lithuania, and Slovakia became the latest countries to introduce Premium E10 (95 RON) at most of their retail stations. This increased the total number of participating EU members to 13 [51].

E10 has been a success in the states where it has been introduced, providing for an increase in renewables in the transport energy mix while lowering the GHG footprint of the fuels. Most cars built after 2000 are compatible with E10. Furthermore, since E10 became the European test fuel in 2016, new cars are not only compatible with E10, but they are also optimised to run on it. This includes all European made cars exported to Australia since then. The only cars incompatible with E10 are older cars such as classic, hobbyist vehicles. These represent a marginal share of the EU fleet and an even smaller fraction of total EU petrol consumption. [51]

A joint declaration by vehicle manufacturers, fuels and alternative fuels representatives stressed that

"European fuel ethanol (...) can be blended up to 10% in petrol (E10) and is compatible for use in all new cars produced for many years now. There is no reason why E10 cannot be more widely distributed throughout the EU". [52]

The EU's renewable energy directive sets a target for 10% of the fuel used in transport to come from renewable sources such as biofuel by the end of 2020 and 14% by 2030. The European Committee for Standardization (CEN) have even commissioned research which concluded at the end of 2019 into the costs and benefits of E20 to help develop new quality and specification standards prior to the implementation in the European market. Ortwin Costenoble, a senior standardisation consultant at the Royal Netherlands Standardization Institute (NEN) which led the project, stated:

"The conclusion we have reached is that all the vehicles coming onto the market and those since 2011 should be able to handle fuels with up to 20% ethanol".

The project was completed with the major assumption that in 2030 countries would adopt E20 as the main source of fuel. [51]. The European Automobile Manufacturers Association also provides a vehicle compatibility list. It includes Japanese vehicles and was current as of August 2018. [50]

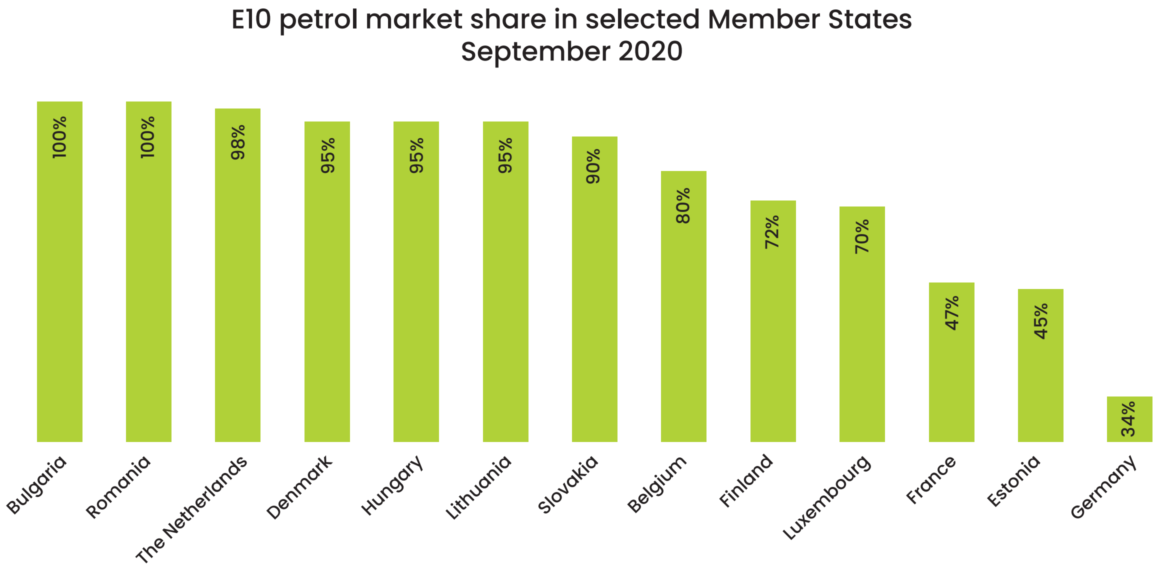


Figure 11: E10 market share in Europe [52]

Notably the use of E10 ethanol fuels in Australia dates back to 1929.

EXISTING ETHANOL PRODUCTION

Overview

Existing Australian ethanol production capacity of 436ML per annum, (Table 4) is not sufficient to meet the mandates currently in place in Queensland and NSW (607 ML per annum). Whilst mandates have not been met for several reasons, the NSW government has just renewed the mandate and committed to increased efforts to achieve the mandate. Achieving the mandates would require an additional 170ML per annum of production.

To meet the aromatics reduction legislation, it is predicted that potentially an additional 423ML of ethanol will be required per annum in 2022 increasing to 550ML by 2030 to replace 7 % of premium unleaded petrol (95 and 98) sales in Australia. This represents a substantial increase in demand for ethanol in Australia. We have a unique opportunity to meet this demand with Australian supply.

Current Australian Ethanol Production:

Plant	Location	Feedstock	Production Capacity (ML pa)
Manildra Group's Shoalhaven Starches	Nowra, NSW	Wheat, waste starches	300
United Petroleum Biorefinery	Dalby, Queensland	Sorghum	76
Wilmar ethanol distillery	Sarina, Queensland	Molasses C	60

Table 4: Existing Australian Ethanol Production Capacity

Australia's three existing ethanol plants have minimal impact on food supply due to their use of low value agricultural co products as feedstock.

Whilst Sorghum is used an animal feed, the Dalby plant only utilises the starch component. The protein and fibre content are separated, dried and on sold to the feed lots as distillers' grains. This product is valued as a high protein feed.

Although Australian ethanol production capacity amounts to 436 ML per annum, 72% of the domestic production required to meet existing mandate targets, existing production rates only amount to about 250 ML per year though, which is crippling the industry by forcing plants to work at 50-60% capacity. Strong government support to achieve mandates is critical for the industry.

By contrast, worldwide production of ethanol in 2019 was 115 billion litres, with the United States accounting for 59.5 billion litres and Brazil accounting for 36 billion litres [31].

To give an indication of the size of Australian ethanol production in comparison, Figure 12 shows the scale based on 2015 production data. Australia's bioethanol production capacity was 0.48 per cent of global bioethanol production in 2018, which remains close to the whole period from 2015-2020.

Chinese ethanol production reached 3.9 billion litres in 2019 and is expected to keep growing as E10 rolls out to more provinces. The government had planned major rollout to be enforced by the end of 2020, however, has delayed due to the depletion of China's previously large grain reserves. Eight provinces currently offer complete E10 coverage with another six in the process of expanding availability [31].

Australia's current approach to biofuels has largely been passed on to the market to implement. The Federal government has provided excise subsidies which are now being phased out and Queensland and NSW have implemented mandates with sales targets.

Most existing dispensers can accommodate four products and historically these have been allocated to RULP, PULP95, PULP98 and Diesel. The introduction of E10 requires one of the existing products to be converted to accommodate E10. Most service stations appear to have elected to alternate E10 and RULP nozzles leaving PULP95 and PULP98 available at all refuelling positions. IPART reports that approximately 53% of nozzles dispense E10 [75]. Notably E10 sales actually exceed PULP and PULP98 sales in both Queensland and NSW [11].

In light of the renewed commitment from the NSW Government for the implementation of existing mandates, it has been assumed that spare capacity within existing production should be reserved for servicing existing mandates and that additional production be considered to meet expected 2030 demand from aromatics reduction.

Expansion Opportunities

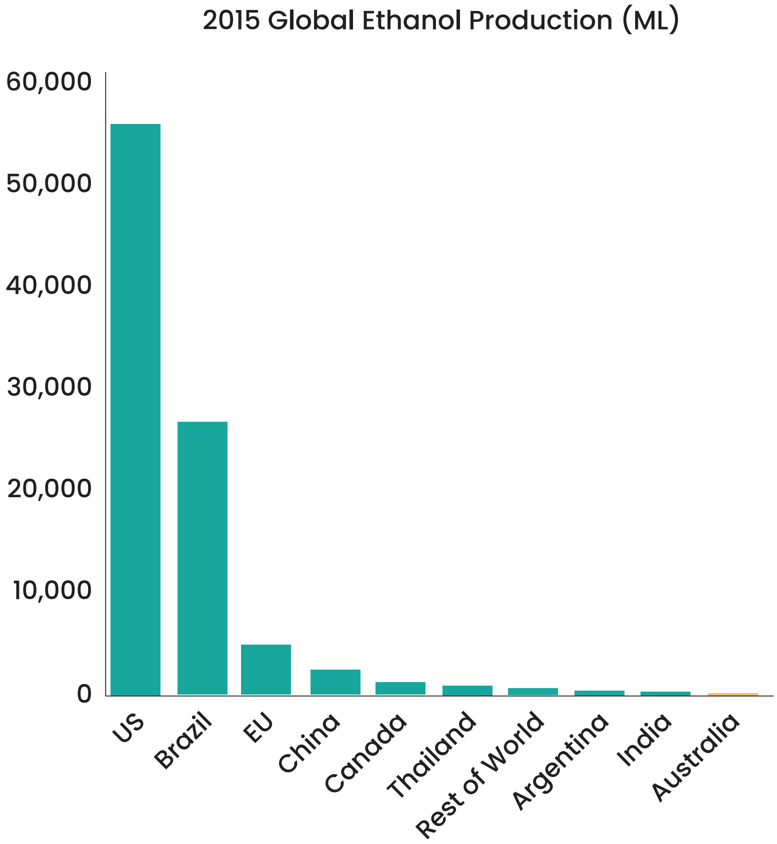


Figure 12: 2015 Global Ethanol Production [18]

The ability of existing plants to expand production to achieve the potential demand is considered limited.

- The largest ethanol plant, operated by the Manildra Group at Shoalhaven in NSW, has already undergone several expansion upgrades to reach 300ML per annum.
- The Wilmar distillery at Sarina is 93 years old and has already undergone some upgrades in recent years. However, the main limitation for expansion is considered to be the available supply of molasses C which the authors understand is already sourced from other sugar mills as well to supply existing feedstock demand.
- The Queensland Government recently provided a grant for the Dalby Biorefinery to perform a feasibility to expand to 100ML pa. This represents a small percentage of the total potential increase in demand.

POTENTIAL FOR NEW ETHANOL PRODUCTION

Potential Feedstocks

Australia has plentiful feedstocks to support additional ethanol production. Whilst existing feedstocks are diverse including wheat, sorghum and sugar cane molasses, other options include sugar cane juice, barley, corn and biomass via lignocellulosic processing. There has previously been commentary around the world that biofuels compete with food for feedstocks. However, there are several significant arguments here.

- Australia does not have a food security problem [71]. We produce substantially more food than we consume as shown in Figure 13. Overall, 71% of our agricultural production is exported.

Figure 13: Australia's food security [71]

- The production of ethanol from grains has negligible impact on the market availability of the nutritional protein and fibre components. Only the starch component is utilized to produce sugars for ethanol leaving the proteins and nutrients for food. Ethanol production facilities based on starch sources can be considered multi-product biorefineries that upgrade the protein content of the original seeds, and generate additional high value products such as oil (e.g. US corn oil) and high protein feeds [77].

Drought has placed pressure on farmers growing grains, raising prices and reducing production, however Australia has continued to sustain our own needs and maintain exports. Notably from 2010-2020 wheat exports have been two to three times our domestic food needs. However it is important that reliability of supply and the economic considerations of drought are considered when selecting feedstocks for an ethanol plant.

Notably with ethanol production reaching 115 billion litres in 2019, and countries such as the USA having significant export capacity, global ethanol supply chains are available to ensure stability of supply.

Tropical north Queensland which produces most of Australia's sugar has not suffered the same drought conditions and has maintained sugar production levels during this period. Notably most of the sugar produced is exported overseas [69]. However, export prices are low and the economics of the sugar industry are under pressure, illustrated by the recent announcement by Bundaberg Sugar to close the Bingera sugar mill.

Land use

There is always pressure not to increase land use for agriculture, however only 3.7% of the land area in Australia [72] is used for agricultural crops. Notably 71% of this is to support exports, not all of which is used for food. Whilst maintaining our agricultural industry is critical for jobs and regional economies, it makes sense for Australia to benefit instead of other countries.

Notably:

- Up to 90% of our canola exports are used by Europe for the manufacture of biodiesel. [76]

- 86% of our sugar is exported. In a world context Australia's sugar exports are not significant representing only 2% of world production [53]. At a time where the industry is struggling economically, our sugar exports alone could be used to produce 1,900 million litres of ethanol per annum [30]. The world sugar market is currentlyover supplied with Indian product and Australian exports would not cause a shortage if repurposed for domestic use. In fact, Australian producers have been struggling to compete with larger producers.

Australia's Agricultral Industries 2017

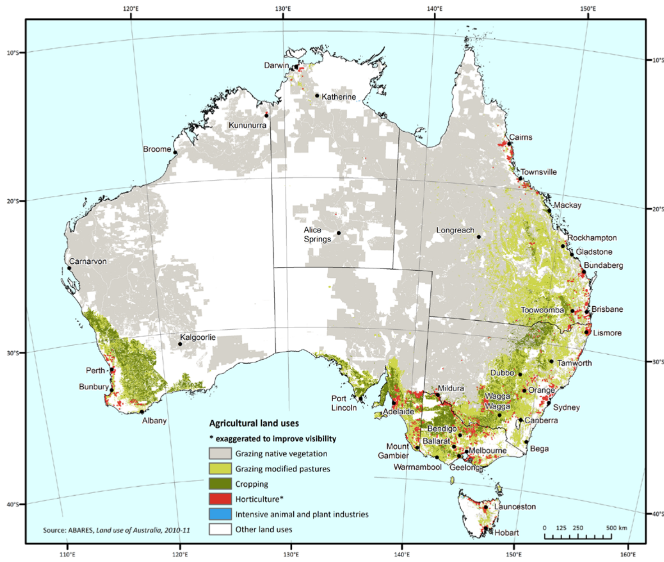


Figure 14: Australian land usage [72]

Ethanol Entrants

Entrants in the Australian ethanol market have been unable to establish market supply offtake agreements with oil companies which are critical to obtain the funding they require from banks. Without direct investment or commitment from the large active oil companies in Australia there is a low probability of funding being granted.

Once capital costs for advanced biofuels has been appreciably driven down, these technologies can be used to augment existing first generation ethanol plants or establish greenfield plants with a combination of first and second generation technologies. Wastes from conventional ethanol production provide the perfect feeds for advanced biofuels plants in a cogeneration scheme once such technologies have further matured. The Jamison Report, 2008, proposed that sugar cane used for exports alone could support five 200ML per annum ethanol plants, however given the land reserves, export levels could be maintained with the available land currently not utilised for sugar cane. Once there is confirmed consistent high demand for ethanol in the Australian market there will be greater potential for Australian domestic production to increase in viability. Implementation of more Australian first-generation bioethanol plants is critical to establishing the industry, increasing consumer acceptance and obtaining social license. [55]

Ethanol producers are poised to invest in biofuel production in Australia, however, require certainty that a plant with a life of 20 years plus will have a long term market and be commercially viable. Existing plants are not even operating at full capacity and this is negatively impacting investor's perceptions. With the introduction of the reduced aromatics legislation there is finally an opportunity to act, with 113-550ML of new potential Australian demand up for grabs by 2030.

Significant entities ready to act in the biofuels industry include:

- MSF Sugar Biorefinery Tablelands, Qld – MSF is utilising the Agave plant which can grow in semi-arid areas without irrigation and does not compete with food crops or place demands on limited water and fertiliser supplies.
- Renewable Developments Australia Pentland, Qld
- Millenium Bioenergia Total flex ethanol plant.
- Austcane Mona Park, Qld
- Dongmun Greentec Deniliquin, NSW
- North Queensland Bioenergy Ingham, Qld
- Mercurius Biorefining: Developing their novel REACH process which converts cellulosic biomass to hydrocarbons in the renewable diesel, aviation and marine fuel ranges.

Some of these possible entrants have proposed new ethanol plants already, as highlighted by Figure 15.

Name	Location	Feedstock	Capacity (ML)	Status
Manildra Group	Nowra, NSW	Starch	300	Operational
United Petroleum Dalby Biorefinery	Dalby, Qld	Sorghum	76 (100)*	Operational (Expansions)*
Wilmar Bioethanol	Sarina, Qld	Molasses	60	Operational
Renewable Developments Australia*	Pentaland, Qld	Sugarcane	350	Proposed
Dongmun Greentec	Deniliquin, NSW	Wheat	~115	Proposed
Austcane	Mona Park, Qld	Sugarcane	~110	Proposed
North Queensland Bioenergy	Ingham, Qld	Sugarcane	30-90	Proposed
MSF Sugar Biorefinery***	Atherton Tableland, Qld	Sugarcane	55	Proposed

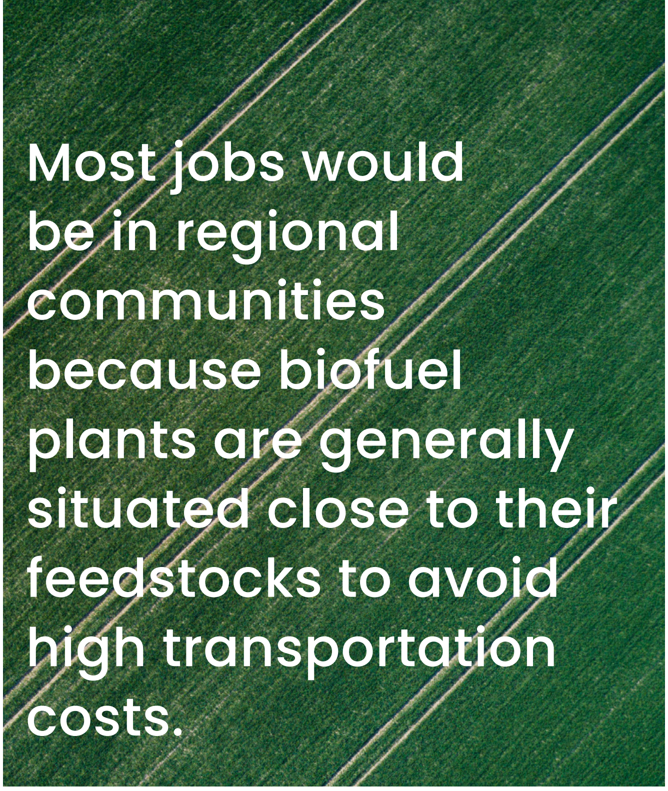
Figure 15 Existing and proposed ethanol plants in Australia as of 2018 [29].

Proposed plants as listed in Figure 15 alone can account for a possible 710ML of new Australian ethanol supply. This could meet expected demand and contribute to Australia's export market for both fuel ethanol and other in-demand markets such as hand sanitisers and other alcohol-based products. Future technology which is rapidly maturing is cellulosic ethanol production from agricultural waste and wood residues. The cost of such technology is being driven down by an industry which is dedicated to reaping the benefits of 90% emissions reductions. The capital cost of cellulosic technology is currently USD 45 per litre of production versus USD 0.5-0.6 per litre for conventional ethanol.

Cellulosic technology costs are estimated to fall over the next ten years to USD 2 per litre by 2030 [14]. As noted previously, first generation plants offer a way forward to implement this technology when ready and mitigate the risk. It is relatively straightforward to retrofit cellulosic technology to a first generation plant to expand production. Importantly, this increases production of ethanol without any increase in land use using unutilised first generation plant waste biomass.

An example of an efficient process for cellulosic ethanol which is in the late stages of demonstration is the Clariant Sunliquid [16] process which uses 5 tons of feedstock to produce 1 ton of ethanol via a fully integrated process which uses optimized biocatalysts and on-site enzyme production. Clariant has acquired license agreements with four partners to utilise their technology, and have experience revamping a first-generation plant to utilise second-generation technology.

Praj and Chempolis are also progressing advanced biofuels which will assist the technology and economics to be proven over the next 5-10 years. Whether or not such technologies will be implemented and capitalised on in Australia depends on the market and associated government support for innovation and implementation of projects in the industry.



BENEFITS OF EXPANDED ETHANOL PRODUCTION

The benefits of replacing aromatics with ethanol extend to facilitating the implementation and growth of a successful Australian bioeconomy. Growth in domestic ethanol demand can be met with domestic supply which will create jobs and investment in regional and rural communities, create additional income streams for farmers, improve vehicle performance, reduce emissions, and increase health, improve Australia's trade balance, enhance energy security and enable Australia to participate in the future behemoth advanced biofuels industry while it is still emerging

Regional Jobs, Economic Investment and Additional Income Streams for Farmers

Economic Investment.

Although current focus is seen to be on future transport in Australia via electrification and hydrogen, the demand for liquid fuel is predicted to remain strong. The Australian Electric Vehicle Market Study [73] predicts that hydrogen and electric vehicles will comprise only 30% of the Australian passenger vehicle fleet in

2040 without direct government subsidies and intervention.

Based on the experience of the Wilmar bioethanol distillery in Sarina, Queensland, a 100ML per annum bioethanol plant will require a capital investment of about A$120 million and create revenue exceeding A$85 million per year, 160 direct jobs and 505 indirect jobs [29]. The revenue spent is predominantly on securing feedstocks, wages and procurement contracts with local service industries, all of which contributes to national GDP. Renewed commitment to mandates in Queensland and NSW can be met by existing production with a 170ML expansion, thus all aromatics reduction ethanol demand should be met via new production. The replacement of aromatics with ethanol will require a total of 113-550ML per normal year based on expected FY30 sales of premium unleaded fuels. The creation of a robust domestic ethanol industry would enable this target to be met easily and pave the way for future growth in line with the government's biofuels roadmaps and commitment to fuel security. Most jobs would be in regional communities because biofuel plants are generally situated close to their feedstocks to avoid high transportation costs.

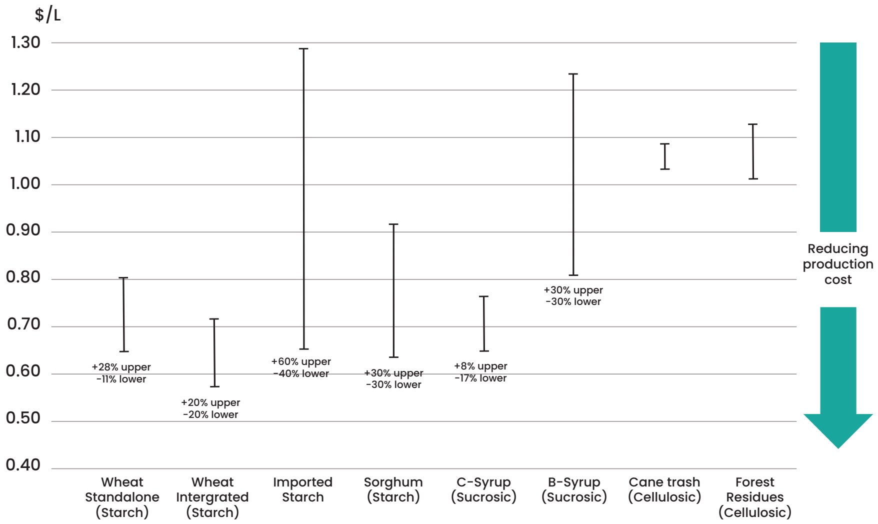


Figure 16 The impact of feedstock cost variation on Ethanol cost [18]

In 2016, the Independent Pricing and Regulatory Tribunal commissioned a report on the efficient operating and capital costs for new entrant producers of ethanol [18]. Strong feed markets are available for ethanol production, as highlighted in Section 9.1. In addition to the feedstocks highlighted in the Figure 16, sugar cane is an ideal feedstock for production of first generation ethanol. Sugar cane at $40/tonne equates to a feedstock cost of $0.42/L ethanol.

An example of a typical plant arrangement is a 100ML per annum bioethanol plant operating with a sugar cane feed, which is estimated to require approximately one million tonnes per annum to operate [74]. The most profitable model for cane processing is an integrated facility which combines fermentation, distillation and vinasse production.

One such viable example of a mill which can benefit from such a scheme is the Bingera sugar mill in Bundaberg which has recently seen a complete closure. A clear opportunity is present for a commercial scale crop-based bio-ethanol site based on the availability of feedstock, access to water, gas/power and stable logistical framework. It is noted that all existing sugar mills are operating at reduced production levels due to poor world sugar prices however, there are a number of opportunities to utilise this spare capacity to implement biotechnologies.

In addition, wheat provides a cost effective opportunity as an alternative feedstock, as highlighted in Figure 16. The most profitable model for wheat processing is an integrated facility which combines flour milling, gluten production, ethanol refining and feed production for animal feed in rural areas.

Regional Jobs

The benefits of a successful biofuels industry are well documented. Worldwide there are 3.6 million people directly employed in the bioenergy industry. Notably 2.1 million of these are within the biofuels industry [25]. With the world production of energy from biofuels and wastes accounting for 10.4 per cent of the total global energy production and the market for bio-based products expected to reach US$1128 billion by 2022, a successful bioeconomy has become a global reality [29].

The USA and Brazil are the two largest biofuel producers in the world. Biofuels support 832,000 jobs in Brazil. In 2019 there were 68,684 direct U.S. jobs and 280,327 indirect U.S. jobs associated with the ethanol industry, which created $23.3 billion in household income and contributed $43 billion to the U.S. national GDP [31]. Biofuels offer diversification of crop use and reduced exposure for our farmers to international dumping practices and influences. Global employment data suggest that an Australian biofuel production target of 20 gigalitres could provide ongoing employment for up to 250,000 people [15].

It is clear that biofuels and bioproduct industries such as ethanol create rural jobs and investment. Stimulating the Australian bioeconomy with the addition of ethanol as Australia's Octane Enhancer will improve public awareness of the benefits of ethanol and invigorate growth in the use of 10 per cent ethanol-blended petrol (E10) across Australia. A recent QUT report [29] identified that widespread implementation of E10 could achieve significant benefits.

- Create 2080 direct jobs and up to 6570 indirect jobs.
- Attract A$1.56 billion of investment.
- Generate more than A$1.1 billion of additional revenue per year in regional communities.
- Potential additional farm revenue from biomass-based industries is between A$3.9 billion and A$7.8 billion per year currently, increasing to A$5.7 billion to A$11.4 billion per year in 2050.
- Further to improving Australia's balance of trade by about A$1 billion annually, the substitution of 10% of Australia's petrol consumption with domestically produced bioethanol has the potential to reduce petrol imports by up to 18%.
- The above data has been extrapolated to estimate the economic benefits for the use of ethanol to reduce aromatics and summarised in Table 5. There is also the potential to improve Australia's balance of trade by up to A$300 million per annum and reduce petrol imports by up to 8% [11].

		6 new ethanol plant (600ML) Scenario 1	1 new ethanol plants (100ML) Scenario 2	3 new Ethanol plants (300ML) Scenario 3
	Capital Investment	$720 million	$120 million	$360 million
	Yearly Revenue	$510 million	$85 million	$255 million
Jobs	**Direct Jobs (Regional)**	960	160	480
Jobs	**Indirect Jobs (Broader economy)**	3030	505	1515
Jobs	**Total Jobs**	3990	665	1995

Table 5: Potential Economic Investment and Jobs created by new domestic ethanol plants [29]

Additional income streams for farmers

For many farmers, fuel is the highest cost when considering overall operational costs. Australian farmers are well-placed to capitalise on the growing biofuels industry by providing their waste materials as feedstocks. Over 78 million tonnes of biomass are potentially available to use in Australia right now, with expansion of up to 100 million tonnes predicted for 2030 (29). Four refineries planned for Queensland propose to use sugarcane (Figure 15) while a refinery planned for Deniliquin, NSW will use surplus and low-grade wheat. This plant by Korean biofuel producer Dongmun Greentec is a perfect example of the impact of new biorefineries on the local economy. The plant will cost more than $77 million and provide 350 local jobs during construction and 50 jobs in operation [57]. There are many sources of biomass which are available for use as feedstock. When an average biomass price of between $50 and $100 per tonne is assumed, this results in possible additional revenue streams available to farmers of between $3.9 billion and $7.8 billion [29]. Bioethanol can be produced from crop residues including stover, sugarcane bagasse and cane trash, forestry residues, and horticultural residues (Figure 17).

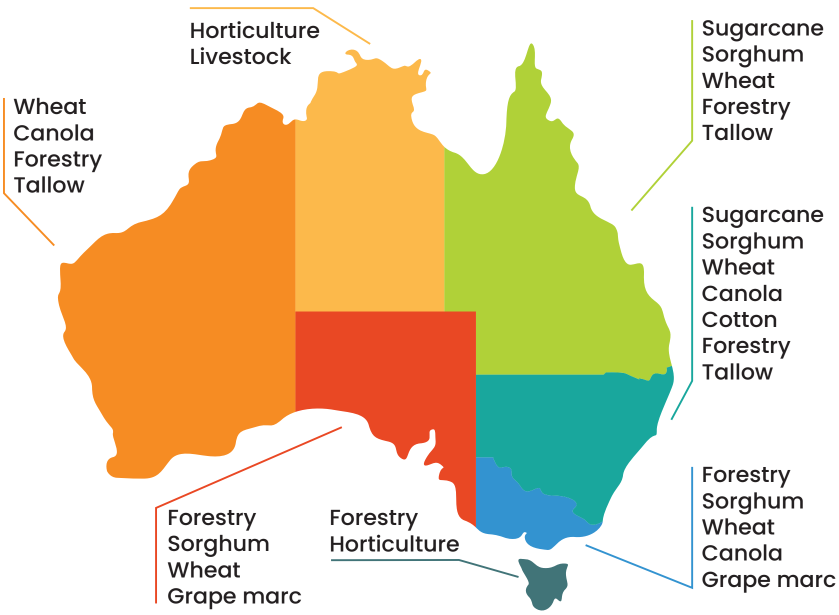


Figure 17: Sources of biomass for future bioethanol production – Adapted from [29]EPA [28]

Huge potential for added value exists for farmers where the sources of biomass are waste residues or by-products of farming. Farmers will have the opportunity to integrate their waste streams with biorefineries to maximise revenue. Therefore, establishing biorefineries to produce ethanol can benefit local farmers by increasing the value of their produce. Furthermore, animal feeds represent a significant portion of the production costs of livestock, with average estimates at 70%. The generation of protein- and vitamin-enriched yeast biomass as a by-product of ethanol production provides added value to local animal industries in the vicinity of the biorefinery. Thus, added ethanol production can meet growing industry demands for alternative protein sources for both commercial and feedlot feeds [17].

Reducing emissions

Ethanol is non-toxic, biodegradable and does not permanently affect the water table. Unlike some components of gasoline such as benzene, ethanol is not carcinogenic. Bioethanol is the cleanest alternative for increasing the octane content of petrol. Ethanol use at up to 10 per cent in petrol in Australia can reduce total greenhouse gas emissions by 2.6 million tonnes CO2eq per year [29]. Thus, expected savings due to implementation of aromatics reduction is expected to be in the order of 0.8 million tonnes CO2eq emissions reduction in Scenario 1, 0.2 million tonnes in Scenario 2, and 0.5 million tonnes Scenario 3.

Several Australian oil refineries have closed in recent years

Year	Refinery	Capacity (bpd)	Location
2009	Closed: ExxonMobil Stanvac refinery	100,000	Adelaide
2011	Closed: Shell Clyde refinery, coverted to import teminal	100,000	Sydney
2012	Closed: Caltex Kurnell refinery, coverted to import teminal	124,500	South of Sydney
2014	Closed: BP Bulwer Island refinery, coverted to import teminal	90,000	Brisbane
2018	Operational refineries: BP Kwinana Caltex Lytton ExxonMobil Altona Viva Geelong	 138,000 104,000 75,000 130,000	 South of Perth Brisbane West of Melbourne Geelong
2021	BP Kwinana refinery closure announced ExxonMobil Altona refinery closure announced		

Figure 18 : Recent history of Australian oil refining. Image: Maritime Union of Australia [60]

Particulate Matter

E10 use reduces vehicle exhaust particulate emissions by 26 per cent, with associated health benefits. The sulphur reduction associated with reduced aromatics results in better catalytic converter performance and reduced NOx emissions and CO emissions, both of which have large environmental effects associated with emissions [28]. Typically, reducing aromatics will also result in reduced sulphur. Ethanol also reduces Particulate matter (PM), which is uncombusted harmful particles. Formation of PM is heavily accounted for by the aromatics content of gasoline and increases in the oxygen content of the fuel has been shown to decrease emissions of harmful particles [5]. The US EPA's REMSAD model for particulates and also the Caltech secondary organic aerosol model both assume that all PM comes solely from aromatic compounds, which lends strength to the argument that use of ethanol in place of aromatics is expected to reduce harmful Particulate Matter emissions [5].

Aromatic toxicity

Analysis of fuels with the EPA Complex Model indicates that a 10 percent ethanol blend can reduce benzene by 25% compared to conventional gasoline. Furthermore, mass-based total toxic emissions are reduced by 13% while the total toxics risk is reduced by 21% when the toxicity of the chemicals involved is taken into account [5]. This reduction is attributed to the dilution, octane increase and oxygen provided by ethanol.

Greenhouse gas emissions

From an industrial perspective, the substitution of reformation intensity to produce high aromatics in traditional fuel with conventional bioethanol plants is shown to reduce life-cycle production emissions by an average of 51% through well-to-wheels analysis [8, 38]. Ethanol typically reduces greenhouse gas emissions by 39% - 96% with sugarcane typically 51% and cellulosic feed stocks achieving the greatest reductions in the order of 96% [38]. This is highly dependent on the quality of the crude oil, finished E10 composition and ethanol feedstock and production process. Life Cycle Analysis can be used on a case-by-case basis to demonstrate that ethanol facilities are operated in a way to secure actual emission reductions.

Sustainability

Ethanol is energy positive with grain stocks producing 61% and sugarcane 332% more energy than the fossil energy required to produce them due to utilising solar energy absorbed by plant feed stocks [38]. Relative to petrol, sugarcane can reduce the fossil energy use by 96% and cellulosic feed stocks even more. Therefore, ethanol production can be self-sufficient in terms of energy, or even a net energy exporter if clever energy integration strategies are employed. Furthermore, all feedstocks for ethanol production are renewable and can be replanted in yearly cycles with efficient crop rotation strategies.

Enhancing Fuel security

Australia currently imports around 90% of our liquid fuels, for a negative trade balance of over A$25 billion [3]. While we have enjoyed 40 years without a major disruption, we need to be prepared for unforeseen threats. Under our obligation as IEA members, we need 90 days of fuel stocks. We have 80 days if fuel on the way to Australia or held overseas by Australian companies is counted, however under current IEA methodology this is not allowed to be counted as stock we hold ready to use. Consumption cover of petrol, diesel and jet fuel has been consistent over the last decade, ranging between 17 and 20 days on average [3].

In October 2020 BP announced their Kwinana Refinery in Western Australia will close and recently ExxonMobil announced their Altona refinery will close. BP and ExxonMobil's decision will result in bringing the tally to six oil refineries having closed out of Australia's original eight. Five of these closures occurring in the last ten years.

To maintain viability Australia's two remaining refineries must adapt to global conditions, including blending of the cheaper blend stock for oxygenate blending to maintain margin. This has happened in the US over the previous years, ever since the Renewable Fuels Standard Program was created under the Energy Policy Act of 2005 [60].

The change from 25% blending of ethanol with petroleum blend stock for oxygenate blending (BOB) to 90%

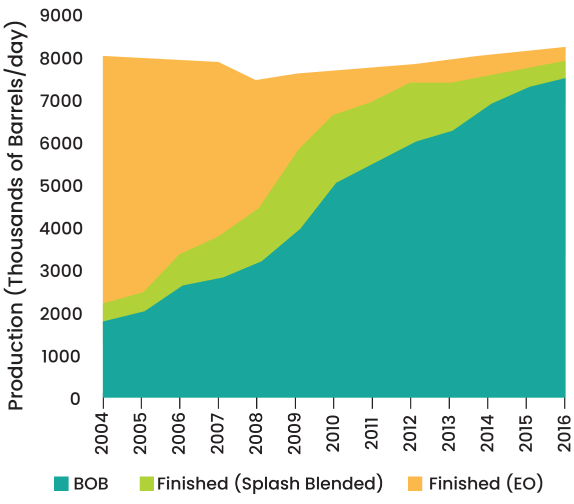


Figure 19 : Recent history of Australian oil refining. Image: Maritime Union of Australia [60]

(Figure 19) represents a major shift in US refining which Australian refineries need to embrace to maintain viability with increased competition internationally. Aside from fuel security, Australia should maintain its domestic production of bioethanol to meet existing mandates and for other end-uses, such as use as the active ingredient in hand sanitiser. Notably, Australian ethanol producers were able to react when COVID-19 stopped Chinese and US supply chains for over a month in 2020.

The Australian government is committed to increasing the fuel security of Australia, as shown by their recent announcement of a comprehensive fuel security package. This follows from the decision in April 2020 to buy crude oil at historically low prices to help Australia boost its oil holdings. In a joint media release titled "Boosting Australia's fuel security" on the 14th September 2020, Minister for Energy and Emissions Reduction Angus Taylor confirmed $211 million of investment in building new domestic fuel storage and backing local refineries. The government is committed to working with industry over the coming months from 2020 to 2021 on the legislative and regulatory design of the new fuel security package. This dedication to improved fuel security is a message to domestic industry that their production is valued, which is vital for continuation of strong Australian production and maintaining a healthy balance of trade. Biofuels and bioethanol can be major contributors towards the improvement of Australia's domestic fuel security and help reduce reliance on imports. [61,62,63]

The establishment of six new 100ML ethanol plants would increase Australia's domestic ethanol capacity to 1,036 ML per annum representing over 6% of total fuel demand. Whilst this will not significantly increase our days cover it is meaningful in that 6% of Australia's petrol requirements are produced locally on a sustainable basis which is not susceptible to interference due to international events or disruptions.

In many ways this is just as important as having storage of crude oil in reserve as it ensures continuity of supply.

Building a resilient future with ethanol as the new "crude oil"

Ethanol is not just suitable for blending into fuel as an aromatics replacement or oxygenate. It is a pure molecule that is a fuel and a pre-cursor for a range of industries into the future. Some of these include:

- A replacement for diesel in long haul trucks (e.g. Scania [78]).

- A high performance fuel on its own, such as in E85 car racing fuel.
- Addition of ethanol to lignin from a lignocellulosic biorefinery to produce low sulphur marine fuel.
- Dehydration to ethylene for production of plastics.
- Catalytic conversion to butadiene, a base chemical for tyres and hoses etc.
- Catalytic conversion from alcohol to jet fuel.

CONCLUSION

The proposed shift in the fuel standards presents a viable mechanism for the increase in usage of ethanol within fuels in Australia. The Department of Environment and Energy's 2022 implementation of pool aromatics reduction from 42% to 35% and possible further total cap of 35% in 2027 may come with challenges but Australia is well placed to handle these challenges. The implementation of ethanol as Australia's Octane Enhancer will assist Australian refineries and mills alike to remain viable.

Reduction of aromatics levels using ethanol can generate significant economic and political benefits depending on the extent of reduction. Based on the Australian premium fuel sales 2030 scenarios, Australia will potentially require an additional 113-550ML of production capacity. This is an opportunity for integrated sugar mills and ethanol refineries to partner with oil companies to holistically profit from cross-industry production. Oil companies can also benefit from lowering their reformer costs and utilising ethanol.

The addition of up to six new ethanol plants of 100ML per annum production could result in a best-case of 3,990 new jobs, $720 million in new regional investment and $510 million in yearly revenues. In reduced minimum base case aromatic reduction scenarios based on lower aromatic content in fuels than the legislative pool maximums, one new plant is still required to meet potential minimum demand of 113ML. This could result in at least 665 new jobs, $160 million in new regional investment and $85 million in yearly revenues.

Alternatively, larger plants can benefit from economies of scale. Either way, the increase in Australian production of ethanol is predicted to result in improvements in Australia' balance of trade, reduced emissions and improved fuel security.

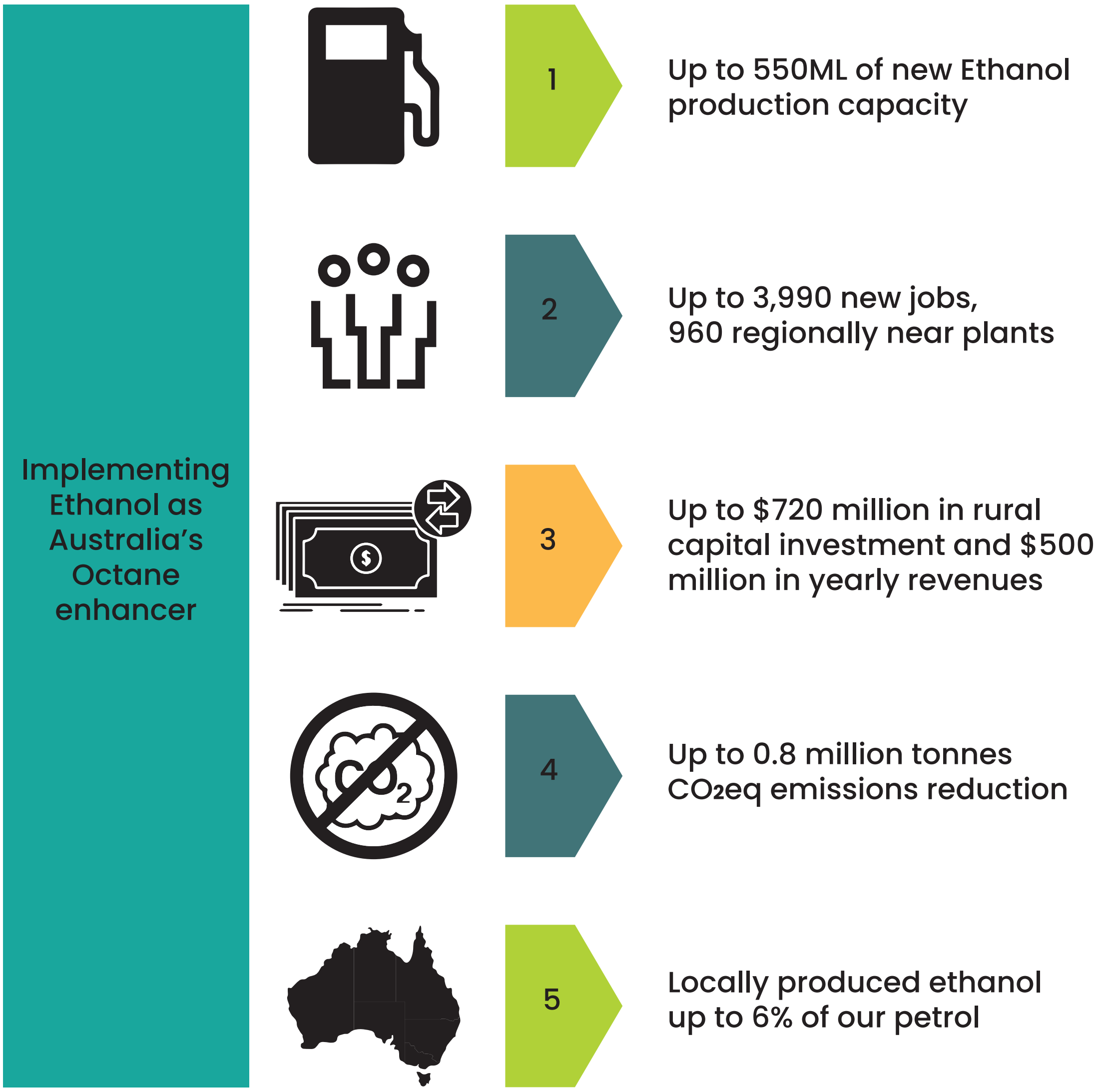


Figure 20: Benefit summary

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ABOUT BIOENERGY AUSTRALIA

Bioenergy Australia is the national industry association, committed to accelerating Australia's bio economy. Our mission is to foster the bioenergy sector to generate jobs, secure investment, maximise the value of local resources, minimise waste and environmental impact, and develop and promote national bioenergy expertise into international markets.

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