

Introduction of E10 Gasoline to Ireland Supply Chain Implications

Report for EERL – Chris Brown

5 October 2018

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Glossary and Abbreviations

% v/v	Percentage on a volume basis
AKI	Anti-Knock Index, also called PON or (R+M)/2
ARA	Amsterdam, Rotterdam and Antwerp
BOB	Blend stock for Oxygenate Blending
cbm	Cubic metre or m ³
Crude oil	A complex mix of hydrocarbon, also called petroleum
DCCAE	Department of Communications, Climate action and Environment
DWT	Deadweight tonnage - the weight in tonnes of the cargo, fuel, dry provisions and supplies carried on board a vessel
E5	Gasoline/petrol grade containing up to 5% ethanol on a volume basis
E10	Gasoline/petrol grade containing up to 10% ethanol on a volume basis
E70, E100, E150	Evaporation at 70°C, 100°C and 150°C, set in the specification as a minimum and maximum volume percentage
EC	European Commission
EERL	Ethanol Europe Renewables Limited
EIA	Energy Information Administration
EN228	European Standard for unleaded 95 RON gasoline
EU	European Union
Eurobob	Ethanol-free gasoline base blend traded in Europe prior to ethanol being added that will meet European standard EN228 after addition of ethanol
FQD	Fuel Quality Directive
Gasoline	Petrol, also called motor spirit
IEA	International Energy Agency
IPIA	Irish Petroleum Industry Association
kt	Thousand tonnes
m ³	Cubic metre or cbm
MON	Motor Octane Number, a measure of octane at high temperatures and speed

NORA	National Oil Reserves Agency, the Irish stockholding agency
PDC	Petroleum Development Consultants (www.pdc.uk.com)
Petroleum Products	Hydrocarbon based products derived from crude oil
PON	Pump Octane Number = $(RON+MON)/2$. Also called Posted Octane Number
$(R+M)/2$	$(RON+MON)/2$
RBOB	Reformulated blend stock for Oxygenate Blending
RON	Research Octane Number, a measure of octane at lower temperatures and speed, and more representative of acceleration behaviour
Vapour pressure	A measure of volatility and important for aiding cold starting for gasoline engines
wt%	Weight percentage

1. Executive Summary

1. Increasing the share of renewable energy and reducing greenhouse gas emissions from the transport sector are important obligations for EU Member States to meet their commitments on climate change. In line with this, Ireland is proposing a biofuels blending target for 2020 for the transport sector that raises the current biofuel obligation rate from 10% in 2019 to around 12% from 2020. The introduction of gasoline with up to 10% ethanol content (an “E10” grade), replacing the current grade which has up to 5% ethanol (“E5” grade) is a logical way to move towards meeting such a new target.
2. The gasoline market in Ireland has a structural deficit and is supplied through production at the Whitegate refinery in the south of the country and imports from the UK and other European countries. Overall demand has fallen, partly due to the economic crisis from 2007 and, as in other European countries, increased use of diesel engine cars over gasoline engine cars, a mature market with improvements in fuel efficiency and the introduction of hybrid and electric vehicles. The decline in demand is expected to continue.
3. Ireland meets its deficit in gasoline through imports but the country also exports; such two-way trade is common and driven by the relative economics of trading with different markets. The UK has been and remains the dominant supplier of gasoline imports to Ireland, reflecting its surplus market position and relative proximity. Other import sources are France, Netherlands, Belgium, Spain and Scandinavia.
4. Ethanol has a strong tendency to bond with water and so it is usually added to ethanol-free gasoline blends at a late stage in the supply chain, often on the road loading rack where road trucks are filled for final delivery to retail sites. This is because there is often some water present earlier in the supply chain and it is desirable to prevent the water coming out of the gasoline blend, resulting in a deterioration in the remaining gasoline. Gasoline is traded internationally mostly in the form of a blend stock for oxygenate blending or “BOB”. This is an unfinished gasoline blend, that is formulated for European markets so that when ethanol is added near the point of final sale, the finished gasoline is compliant with the EN228 gasoline specification¹.
5. Current EU regulations permit up to 10% ethanol in gasoline blends. Several EU countries already have E10 gasoline as the main grade, with up to 10% ethanol content although others including the UK still have E5 gasoline as the major grade.

¹ See details of quality specification in Section 3.3.

6. The addition of ethanol to a BOB changes various fuel qualities including the octane, vapour pressure and density. The final blend must meet all the EN228 specification for gasoline in Europe hence it is important that the BOB is formulated to be appropriate for the addition of the desired amount of ethanol. So, an optimised E5 compliant BOB will be slightly different from an optimised E10 compliant BOB.
7. It is possible to produce E10 by adding (“splash blending”) more ethanol to current E5-compliant BOB subject to the overall formulation still being within the specification and this would need the approval of the source refinery and verification through careful testing. An octane saving in the BOB is possible if 10% rather than 5% ethanol is to be added. An optimised E10 compliant BOB would have a lower required octane than for an optimised E5 compliant BOB, allowing lower cost petroleum components to be used in the base blend. Splash blending ethanol onto to E5 to make E10 will result in “octane giveaway” but the other parameter limits of the fuel specification (vapour pressure, density, sulphur, other hydrocarbon limits) will need to be checked.
8. European refineries are already producing different gasoline blends and BOBs for different export markets as well as for their domestic markets where E5 and E10 gasoline grades are simultaneously available. The UK, a major source of supplies for the Irish market, is also a significant exporter of gasoline to the US where the market is almost entirely E10 grade. Hence, for the Irish market, there is security of supply.
9. Refiners in the UK and other European countries are already in a competitive position to supply the Irish market with appropriate gasoline blends to make an E10 finished gasoline with up to 10% ethanol being added prior to road truck loading in Ireland.
10. The current relative pricing of gasoline and ethanol, combined with the option of using lower costs base gasoline blend, indicates that there is little or no additional cost of using an increased amount of ethanol, as would be needed if making E10 gasoline rather than E5 gasoline.
11. Current production of E10 BOB in Europe and the existing pattern of gasoline blend exports means:
 - a. Ireland can source all its E10 BOB import requirements from France or Belgium if required

- b. UK refiners already supply E10 markets worldwide and would most likely make the economic decision to adjust the quality of BOB exports to Ireland to ensure they continue to capture these exports rather than allow these to be source from continental Europe
- c. Whitegate refinery would adjust its gasoline production to make E10 BOB for distribution by vessel or barge direct from the refinery to other Irish ports and to provide finished E10 gasoline via road truck to the local market area

2. Introduction

- 12. Increasing the share of renewable energy and reducing greenhouse gas emissions from the transport sector are important obligations for EU Member States to meet their commitments on climate change. Some of this will be met through the introduction of electric vehicles, fuel efficiency improvements and other technological advances. However, use of biofuels in the existing fleet of vehicles has to date been the most important measure taken and most Member States are setting increasing renewable energy targets, usually in the form of obligations on fuel distributors to blend a certain percentage of biofuels
- 13. Ireland is proposing a biofuels blending target for 2020 for the transport sector that raises the current biofuel obligation rate from 10% in 2019 to around 12% from 2020. The Biofuels Obligation Scheme was set up in 2010 to help deliver Ireland's National Renewable Energy Action Plan and also meet international commitments under the Renewable Energy Directive and Fuels Quality Directive.
- 14. For petrol to have a certain renewable content, alcohols such as ethanol can be added. The usual approach is to add bio-ethanol i.e. ethanol from renewable sources, most commonly made by fermentation of the sugars in grain and beet crops to produce ethanol. Whilst at a retail level, consumers in Ireland and the UK refer to the fuel as petrol, the generic internationally recognised term for this in the oil industry is gasoline and this terminology will be used here.
- 15. Gasoline with up to 5% ethanol by volume is referred to as E5 whilst gasoline with up to 10% ethanol is called E10. All gasoline in Ireland and the UK currently is E5. This report covers the practical issues around the potential introduction of E10 petrol grade into the Irish market.

16. Globally, gasoline in many countries now contains ethanol though the concentration of this varies from country to country. The reasons for these variations are many but typically reflect the level of interest in ethanol supply on the part of the agricultural sector, local fuel and vehicles standards, and different approaches and attitudes generally to adopting renewable fuels. E5 and E10 grades are widely deployed in Europe and the USA while Brazil has a high proportion of vehicles which run on grades up to 85% ethanol (E85). The range of grades globally indicates that industry, supply infrastructure, policy makers and the automotive sector have all been able to adapt together to the introduction of such new fuels.
17. In Brazil, ethanol is used two different ways:
 - a. As an additive to gasoline, both as a mandatory component of regular gasoline, with the government altering the percentage of ethanol in response to ethanol supply (called E25, with 25% or more ethanol), and as a voluntary component whereby the consumer can add more ethanol to their gasoline to lower their overall fuel cost at the pump (“blender pumping”)
 - b. As hydrous ethanol (96% ethanol and 4% water) which is lower cost than normal gasoline
18. Ethanol's lower energy density does mean that fuel efficiency from ethanol containing gasoline is slightly lower than for gasoline without ethanol. However, this must be considered in the context of reduced harmful emissions, its higher octane level and increases in fuel efficiency over time.
19. Research in the US² suggests E10, common in the US market, has 96.7% of the energy content of ethanol-free gasoline. The same research says E85 has (with an ethanol content of between 51% and 83% depending on geography and season) has 73-83% of energy content of ethanol-free gasoline.
20. Within EU countries, standards agreed through the EC’s Fuel Quality Directive³ specify limits on the amount of renewable fuel that can be blended into gasoline and road diesel fuels. The Directive changed the upper limit of ethanol in gasoline from 5% to 10% in 2012.⁴ This has allowed EU Member States to introduce an E10 grade, a move that already been embraced in Belgium, Finland, France and Germany. Other Member States, such as Ireland and the UK, are

² Alternative Fuels Data Center – Fuel Properties Comparison, 29 October 2014

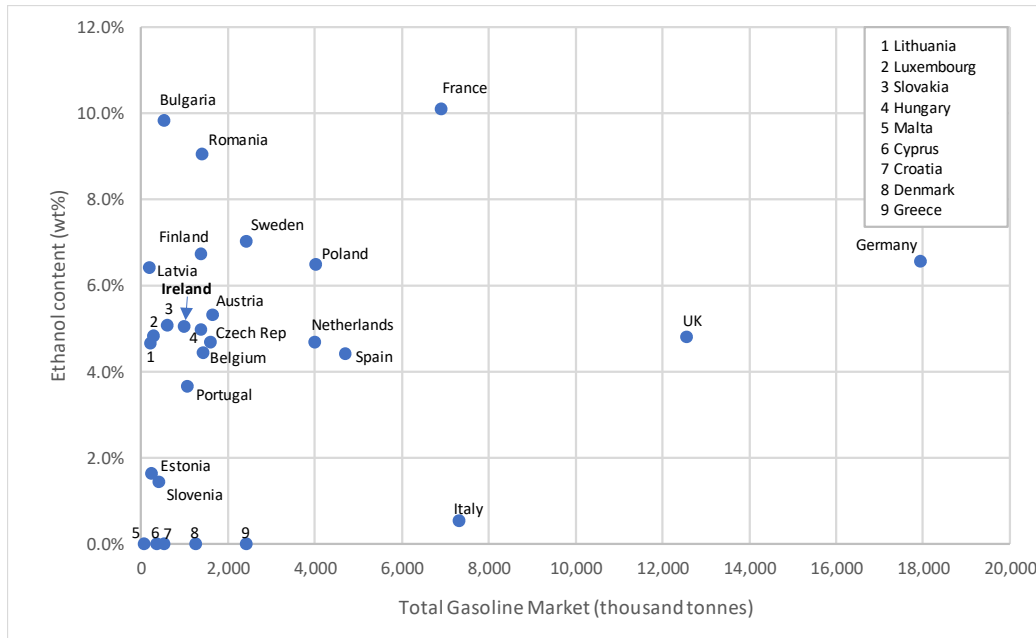
³ Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0030>

⁴ Response by the Irish Petroleum Industry Association, 19 January 2018, to the Biofuel Obligation Scheme consultation process initiated by the Department of Communications, Climate action and Environment (DCCA)

currently still only supplying the E5 grade. Overall, ethanol is established in the EU as a significant component of the gasoline market, at just over 5% of total consumption.

21. The size of gasoline markets and use of ethanol in road fuels across EU countries in 2016 is shown in Figure 1.

Figure 1 Gasoline Markets and Use of Ethanol in EU Countries, 2016



Source: Eurostat

Note: Ethanol content calculated as the consumption of ethanol in the road transport sector divided by the total gasoline (including ethanol) consumption in the road transport sector

22. This report considers
 - a. How gasoline is currently supplied to Ireland through indigenous production and imports
 - b. The ease with which existing infrastructure in Ireland and in countries exporting to Ireland could be used to make a base petrol suitable for E10
 - c. Current practice concerning preparation of gasoline blends for export to various markets
 - d. Quality and blending considerations for moving to an E10 from an E5 grade

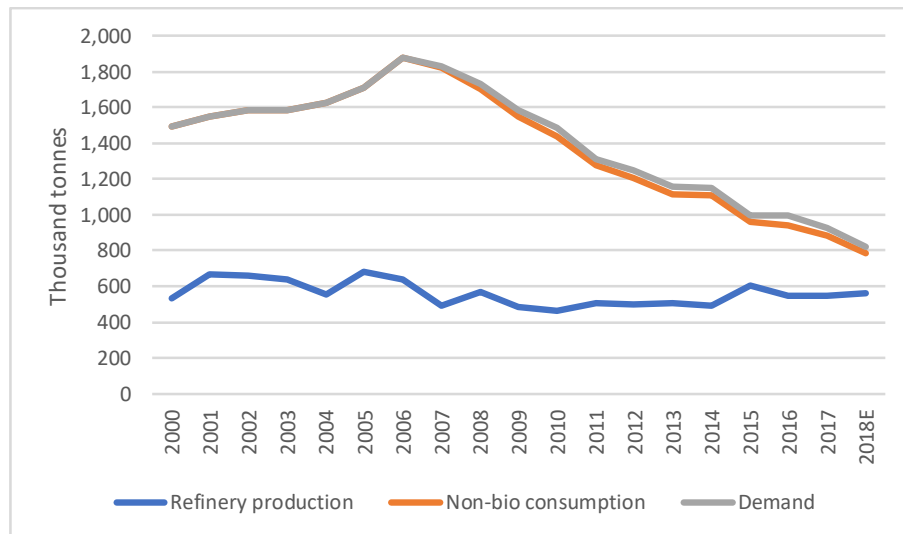
- e. The transition in other countries to gasoline grades with higher ethanol content than in the current E5 grade sold in Ireland and the UK
 - f. Likely cost implications for consumers.
23. This report has been prepared by Chris Brown, BSc, FIChemE, CEng, working for Petroleum Development Consultants ([PDC - www.pdc.uk.com](http://www.pdc.uk.com)). He is a chartered chemical engineer with over 30 years' experience in the oil industry. PDC is an independent international oil and gas consulting company carrying out engineering and commercial studies covering both the upstream and downstream sectors of the international oil and gas industry. PDC has been retained by Ethanol Europe Renewables Limited (EERL) to prepare this report.
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3. The Gasoline Market in Ireland

3.1. Supply and Demand in Ireland

27. The gasoline market in Ireland is supplied through production at the Whitegate refinery in the south of the country and imports from the UK and elsewhere. Structurally the country has a gasoline deficit although this has reduced in recent years due to falling demand.
28. Gasoline supply and demand in Ireland is shown in Figure 2. This illustrates the overall fall in demand since around 2006 and the relatively small amount of demand met through ethanol being added to gasoline blends sourced from refineries.

Figure 2 Gasoline Supply and Demand in Ireland⁵



Source: Eurostat for 2000-2017. PDC Estimate for 2018

29. The difference between the non-bio consumption and demand is the ethanol content of the total road gasoline pool in Ireland. This has risen yearly since 2006 to around 5% by 2017. Demand for ethanol as a blend component in gasoline in Ireland reached 45 thousand tonnes (57 billion litres) in 2017.
30. Gasoline demand in Ireland has been falling for a number of reasons including:
 - a. The economic crisis in Ireland from 2007 that saw GDP growth fall⁶ from +5.2% in 2007 to -3.0% in 2008 and -4.6% in 2009, directly impacting demand for all petroleum products
 - b. Growing popularity of diesel cars leading to a fall in gasoline driven passenger cars from 1.6 million in 2006 to 1.1 million in 2017⁷
 - c. Fuel efficiency improvements.
31. Refinery production has been relatively constant and is from the only refinery in Ireland, Irving Oil's Whitegate refinery in County Cork in the south of the country. The refinery has a reported gasoline production capacity of 20,000 barrels per day⁸ (approximately 865 thousand tonnes/year).

⁵ Annual data to 2016, monthly data for 2017, 2018 estimated from first 6 months data for 2018

⁶ World Bank

⁷ Eurostat

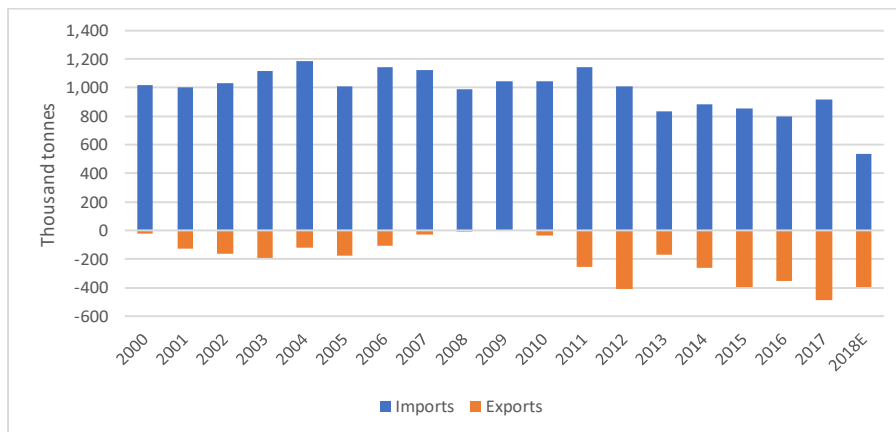
⁸ Irving Oil website: <https://irvingoil.com/en/operations-and-partners/operations/whitegate-refinery>

- 32. Eurostat data show that the peak annual refinery production of gasoline in Ireland in the last 18 years was 683 thousand tonnes in 2005, somewhat below the reported maximum. This reflects many factors including the economic decisions that are taken by refinery management to optimise overall refinery throughput and yields.

3.2. Gasoline Trade

- 33. The difference between refinery production and non-bio gasoline consumption is met through trade. This is in the form of both imports and exports of gasoline, despite Ireland’s overall deficit position. These trade flows are summarised in Figure 3.

Figure 3 Gasoline Imports and Exports for Ireland



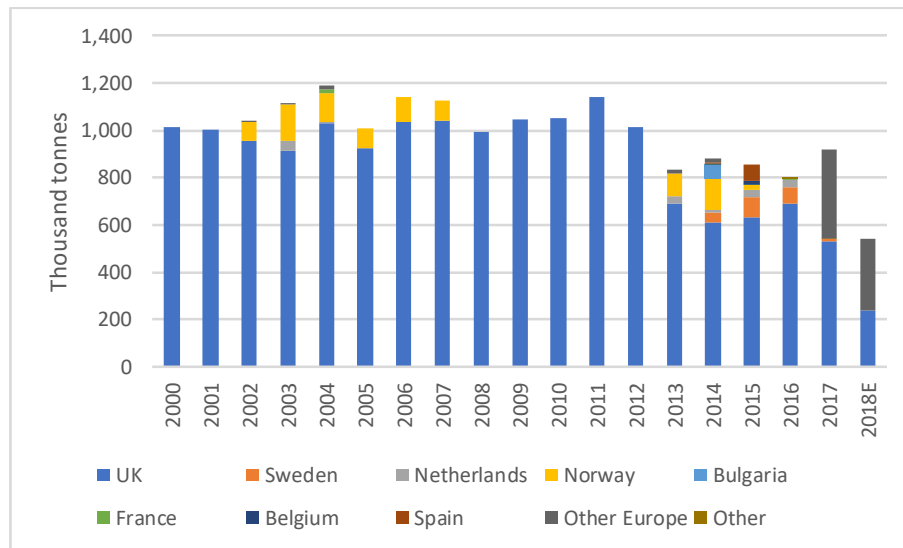
Source: Eurostat

Note: PDC estimate for 2018 due to incomplete data

- 34. Falling demand has led to a partial reduction in imports of refinery sourced gasoline. However, this reduction has been moderated by increased exports over the same period. These are significant at around 400 thousand tonnes per year or about 40-50% of total demand in recent years. It is not unusual for countries that are deficit in a particular product over time to both import and export the product in question. This reflects various factors including seasonality, logistics, the location of refineries versus demand centres and the availability of competitively priced alternative supplies and the value of exported cargoes compared to those sold into the domestic market.

35. Consideration of the sources for gasoline imports, and the destinations for gasoline exports means that oil companies and traders are active in the Irish gasoline market and making complex supply and trading decisions to optimise their operations. It is not simply a case of meeting an obvious deficit through imports. The source of gasoline (non-bio i.e. excluding any ethanol) imports for Ireland are shown in Figure 4.

Figure 4 Source of Gasoline Imports to Ireland⁹



Source: Eurostat

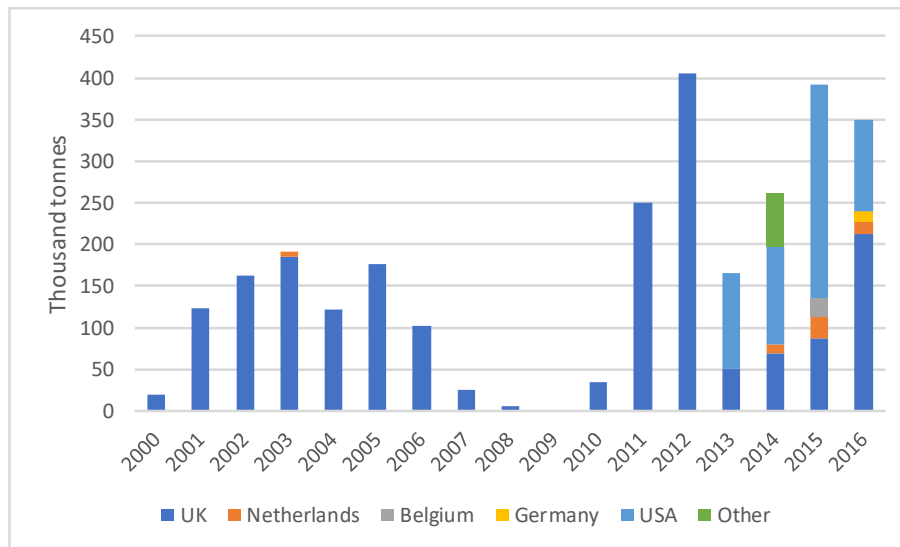
Note: Data for 2017 subject to revision. PDC estimate for 2018 due to incomplete data

36. The UK has been and remains the dominant supplier of gasoline imports to Ireland, reflecting its surplus market position and relative proximity. This is covered in more detail in Section 4 of this report.

37. Ireland’s gasoline exports reflect a need to rebalance the market regionally and not simply meet the national level deficit. They also reflect seasonality and logistic constraints as well as the opportunity to exploit the periodic arbitrage between European and US markets. Gasoline exports from Ireland to various destinations are summarised in Figure 5.

⁹ Non-bio gasoline. Eurostat data of import sources are only available up to 2016

Figure 5 Destination for Gasoline Exports from Ireland¹⁰



Source: Eurostat

38. Exporters are not explicitly identified in the Eurostat data. Exports to the UK or other European markets may be from gasoline traders or the Whitegate refinery. Such exports may be of gasoline blend components which are further processed or blended at their destinations.
39. Exports to the US have emerged in recent years which are most likely to be unfinished gasoline blends in the form of blend stock for Oxygenate Blending (“BOB”) or Reformulated blend stock for Oxygenate Blending (“RBOB”). These are formulated so that when ethanol is added, near the final point of sale, the finished gasoline is compliant with US E10 gasoline specifications. These specifications are different from those in Europe (see Section 3.3).

3.3. Gasoline Quality

40. The standard finished gasoline grade in Europe is set by the European Standard EN228. This standard incorporates the requirement of relevant EC directives that limit harmful emissions.
41. Various gasoline quality specifications are given including the content limits for sulphur, oxygen and ethanol and limits on vapour pressure. The standard also sets other important performance related quality limits such as density and octane. Each country in the EU incorporates European standards into national standards. The UK has BS EN228, Ireland has I.S. EN228 and so forth for each EU member state. A summary of EN228 is shown in Table 1.

¹⁰ Non-bio gasoline. Eurostat data of import sources are only available up to 2016

Table 1 EN228 Specifications

Property	Units	Limits		Rationale/meaning
		Min	Max	
Research octane number, RON		95.0		A measure of the combustibility of a fuel. Higher octane means a higher compression of the air-fuel mixture before spontaneous ignition
Motor octane number, MON		85.0		
Vapour pressure	kPa		60.0	A common measure of volatility. Some volatility is important to help engines start, especially in cold weather. Too much volatility will cause harmful emissions
Density	kg/m ³	720.0	775.0	Performance and economics - effects the composition of the blend and energy content
Sulphur content	mg/kg		10.0	Prevents harmful emissions
Hydrocarbon type content				
- olefins	%v/v		18.0	Prevents harmful emissions
- aromatics	%v/v		35.0	Prevents harmful emissions
- benzene	%v/v		1.0	Prevents harmful emissions
Oxygen content	%m/m		3.7	Performance, vehicle compatibility
Ethanol	%v/v		10.0	Performance, vehicle compatibility

Source: Directive 2009/30/EC, EN228

Note: Vapour pressure value is for the summer and this limit can be increased by means of a waiver reflecting the bioethanol content of the finished gasoline

4. Ability of Other Countries to Supply Ireland

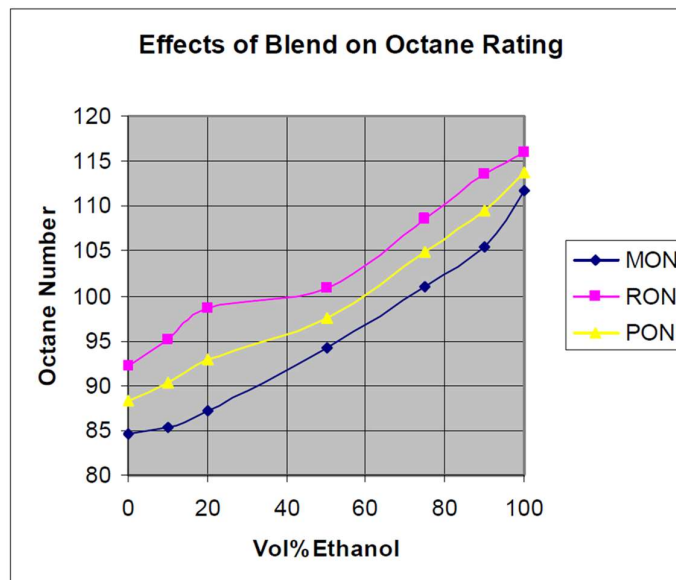
4.1. Quality and Blending Considerations

42. As is common practice, gasoline is traded internationally mostly in the form of a blend stock for oxygenate blending or “BOB”. This is an unfinished gasoline blend, formulated so that when ethanol is added near the point of final sale, the finished gasoline is compliant with the relevant EN228 specification within Europe, or other national standard for other markets.
43. The main reason for this is that gasoline is often transported in bulk and over longer distances by oil product tankers. The holds on these tankers are often wet, i.e. there is water present, and ethanol has a strong tendency to bond with the water, hence coming out of the gasoline blend with a resultant deterioration in the remaining gasoline. As a result, ethanol is not added prior to ship loading from the shore-based tankage, in a terminal or refinery, but instead at a later stage directly into road trucks for final delivery to retail sites.
44. The BOB that is produced needs to reflect the amount of ethanol that is to be added as the ethanol will change several of the product blend’s qualities. In other words, a BOB optimised for making an E5 gasoline grade (with up to 5% ethanol) will most likely be slightly different from that optimised for an E10 gasoline grade (with up to 10% ethanol).

45. Any differences in the quality of BOB produced for E10 versus E5 are driven by the desire to minimise quality giveaway¹¹. This is because gasoline blenders are usually striving to minimise the cost of the overall blend. Ultimately changes to BOB quality, if any, need to be balanced against the quality changes from addition of different levels of ethanol, the blend value of the different components available, the requirement to always meet the finished gasoline specifications and the value associated with any quality giveaway.

46. Ethanol is a good blend component for gasoline as it has a high-octane value. Octane is a measure of combustibility of a fuel. Higher octane means an engine can operate at higher compression of the air-fuel mixture before spontaneous ignition. US research into the addition of ethanol into gasoline blends shows the increase in octane that can be achieved. Figure 6 shows how octane will increase if increasing quantities of ethanol are contained in a standard US gasoline.

Figure 6 Indicative Octane Increase in Gasoline with Ethanol



Source: Ethanol Fuel Properties and Data Page/Bailey and Russel Data for Octane
 Note: Octane increase varies with base gasoline. Here base gasoline composition is unchanged to show the increase attributable to ethanol. In practice, the base gasoline octane would be reduced to maintain a constant finished blend octane with higher concentrations of ethanol. $PON = \text{Pump Octane Number} = \frac{RON+MON}{2}$

¹¹ Giveaway means the quality is better than the required standard but the producer does not get a better price for the product

47. Gasoline is a blend of many components available to a refiner or gasoline trader. Given that gasoline is a freely traded, highly fungible¹² commodity, its price within a particular market and for a particular grade is relatively transparent and fixed at any point in time. Hence the blending operation is optimised by seeking to minimise the cost of making a particular blend.
48. In general, higher-octane components are valued more highly than lower octane components. Availability of higher-octane components will also allow the gasoline blender to use more low-octane, low-value components. As ethanol has a high-octane value, its use can be very helpful in achieving an overall octane level in finished gasoline and can help reduce the cost of the unfinished gasoline blend to which it is added.
49. Further, ethanol also enables countries to meet their obligation towards national targets for renewable fuels use. A comparison between EN228 gasoline and pure ethanol is provided in Table 2.

Table 2 Ethanol and Gasoline Key Properties

Property	Units	Ethanol	EN228	
			Min	Max
Research octane number, RON		~113-116	95.0	
Motor octane number, MON		~110-113	85.0	
Vapour pressure	kPa	15.0		60.0
Density	kg/m ³	789.0	720.0	775.0

Source: Various

Note: For ethanol, the approximate blending octane numbers values are given i.e. the octane within to blend. The octane of pure ethanol is lower.

50. The blending octane value (on a Research Octane Number or RON basis¹³) for ethanol is around 113 but can be higher if blended with lower-octane hydrocarbon blend-stock. The precise blending value of its RON depends on the octane of the final gasoline¹⁴ and the nature of the components it is blended with. The RON specification for EN228 gasoline is a minimum of 95.0. Hence ethanol is an attractive component for blending into gasoline as its use allows other lower octane, lower value components to also be used in the blend.

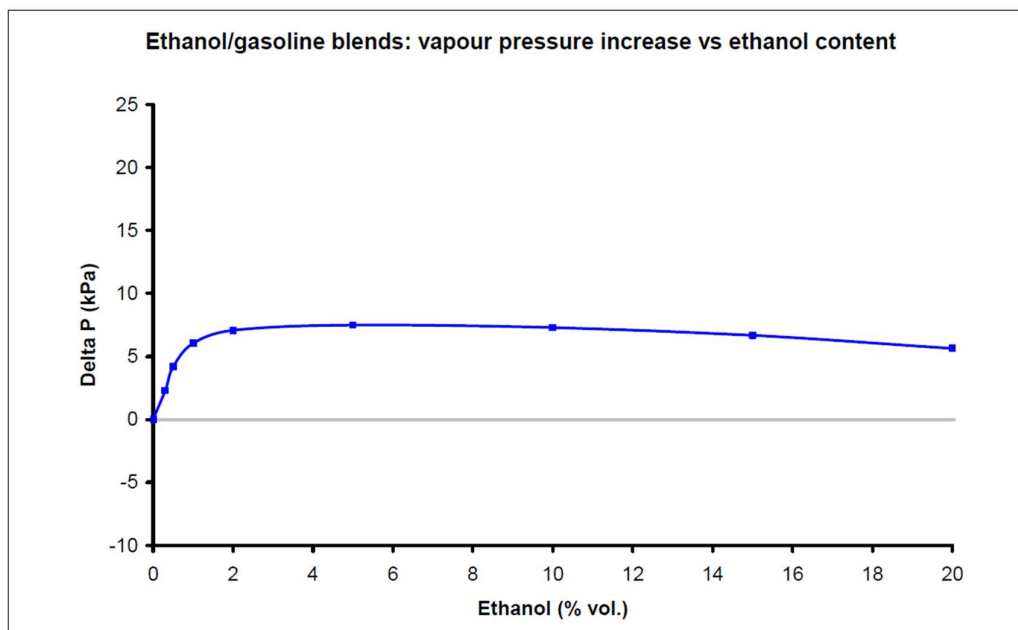
¹² Freely traded and exchangeable

¹³ RON is Research Octane Number and is a specific measurement of octane that describes the behaviour of the fuel in the engine at lower temperatures and speed, attempting to simulate acceleration behaviour

¹⁴ Ethanol and the Economics of Octane, Geoff Cooper, Renewables Fuels Association, 20 October 2017

51. Vapour pressure is an important specification in gasoline as it aids cold engine starting but high vapour pressure can increase harmful evaporative emissions. Research has quantified the change on vapour pressure with increasing ethanol content.
52. Vapour pressure is in part determined by ethanol content but it does not vary in a regular linear manner. Even though pure ethanol has a vapour pressure lower than that for gasoline, it tends in low concentrations to increase the vapour pressure of the finished blended product. As a result, BOB must be produced so that it allows for changes in vapour pressure as well as other changes to other blend properties once ethanol is added prior to road truck loading. This increase in vapour pressure with ethanol content is shown in Figure 7.

Figure 7 Vapour Pressure Increase in Gasoline Blends vs Ethanol Content

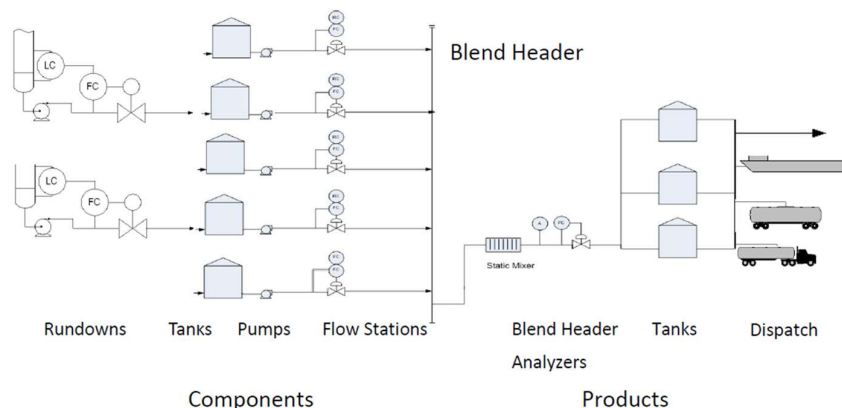


Source: Joint EUCAR/JRC/CONCAWE Study on: Effects of Gasoline Vapour Pressure and Ethanol Content on Evaporative Emissions from Modern Cars, 2007

53. This figure indicates that increasing the ethanol from 5% (E5 gasoline grade) to 10% (E10 gasoline grade) has a negligible impact on the overall vapour pressure of the finished blend. This means that increasing the ethanol content will have a very minor effect on the required quality of BOB needed, at least as far as the vapour pressure specification is concerned.

54. Notwithstanding the lack of any further vapour pressure increase beyond 5% ethanol content, Directive 2009/30/EC sets out in Annex III the levels of vapour pressure waiver that can be permitted for gasoline containing bioethanol as a way of encouraging the use of ethanol in the fuel. This waiver reaches its maximum of 8.0 kPa for 5% to 6% ethanol blends and falls slightly to 7.76 kPa for 10% ethanol blends.
55. The waiver permits producers to blend to a higher vapour pressure limit than for ethanol-free gasoline. The Irish standard, I.S. EN 228:2012 contains such a waiver, so that the finished gasoline in Ireland is required to meet a maximum vapour pressure specification reflecting the actual content of ethanol.
56. In most European countries, refineries have advanced control systems that apply to process units as well as to the management of product blending. Advanced blending control systems permit continuous inline blending and testing of product blends as the various components are mixed in a blend header and run down to a product tank. The advantage of such system is that the blend recipe is set up and continually checked to ensure the product flowing into tankage is on-grade. This avoids repeat testing of the tank as it fills. The product in tank can still be tested but the control over the blend is far superior to when there is only simple in-tank blending. Figure 8 shows schematically how a refinery blends complex products including BOB.

Figure 8 Refinery Product Blending and Despatch



Source: ABB, Refinery Product Blending Optimisation Hydrocarbon Processing IRPC, Milan, 2012

57. For gasoline, BOB is blended and held in product tankage prior to despatch from the refinery. Ethanol is only added on a refinery if being loaded on to road trucks. The logistical issues are covered in more detail in Section 4.2.

58. For the unfinished gasoline blend BOB to be produced, refiners back calculate the required properties so that when a certain amount of ethanol is added afterwards at the loading rack (where BOB and ethanol are simultaneously loaded in to road trucks) the resultant finished product is on-grade. Typically, UK and other European refiners will make a BOB for E5 gasoline that is around 94 RON as 5% ethanol will bring the finished product to 95 RON. A BOB for E10 gasoline would need a slightly lower RON, around 93.
59. The precise BOB specification will need to reflect the particular way that each refiner blends its BOB as the octane uplift that the ethanol will provide will depend on the other components in the BOB. It will also need to reflect the repeatability and reproducibility¹⁵ of the RON tests so a slightly higher octane may be desired for each BOB to ensure that the final gasoline blend is tested within the specification.
60. Other properties need to be considered if a refiner wishes to make BOB for a higher ethanol content gasoline such as density and percent evaporated (E70, E100, E150 etc¹⁶) but these adjustments are easy to calculate and to make and well within most refiners' experience. This is because most refineries are already routinely producing BOBs or finished gasolines for multiple markets with different product specifications. If they want to secure the export markets, they blend appropriately to minimise the costs of each export cargo and maximise profits overall. This is covered in more detail in Section 4.2.
61. It is also worth considering if an E10 gasoline grade can be made by simply adding 10% ethanol to an E5 compliant BOB. This is likely to result in a finished gasoline that is fully compliant with the EN228 specification and this can be verified with the source refinery and/or tested according to standard test procedures. If more ethanol were to be added at the loading rack, directionally the results would be as follows:
 - a. Octane (RON and MON) would increase above the required specification i.e. produce a product in quality "giveaway"¹⁷ but meets the required fuel standards nonetheless
 - b. Vapour pressure may be very marginally lowered, staying within the standard

¹⁵ Repeatability (i.e. same operator/same laboratory) of 0.2 RON, and a reproducibility (i.e. different operators in different laboratories) of 0.7 RON in the relevant test methods (ISO 5164 or ASTM D2699)

¹⁶ Evaporation at 70°C, 100°C and 150°C is set in the specification as a minimum and maximum volume percentage. Not to be confused with the E5 and E10 terminology that refers to the maximum ethanol content in a gasoline blend

¹⁷ Giveaway means the quality is better than the required standard but the producer does not get a better price for the product

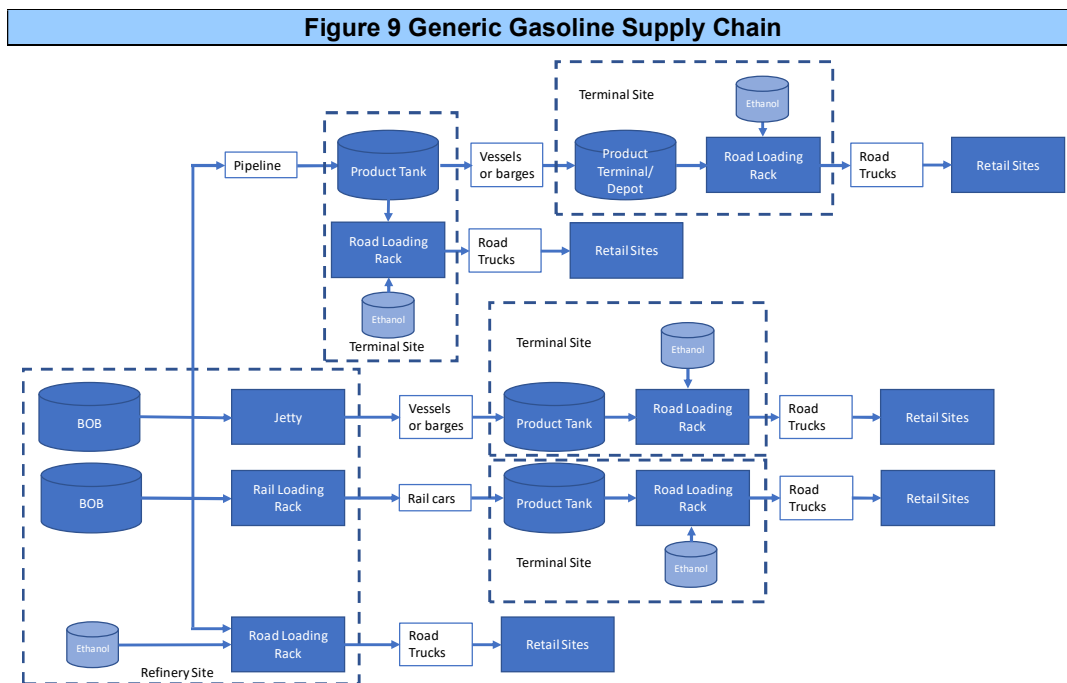
- c. The waiver for higher vapour pressure in the EN228 would be lower and compliance with the new adjusted final specification for vapour pressure would need to be verified
 - d. Other qualities would change marginally e.g. density and percent evaporated (E70, E100, E150) and would need to be evaluated for compliance with the specification, bearing in mind that:
 - i. Refineries tend to produce base gasoline with densities at the lower end of the specification range (as end sale is on a volume basis and lighter blends are hence more profitable) and so addition of an extra 5% ethanol would not take the overall density out of the specification range
- The allowed values for sulphur, olefins, aromatics and benzene are maximums, so additional ethanol can only have the effect of reducing them and hence the finished E10 fuel will be always within standard requirements.

62. What can be concluded regarding blending gasolines with different ethanol content is:

- a. The BOB for an E10 grade gasoline, if optimised to minimise quality giveaway, would be slightly different from that for an E5 grade
- b. There is little, or no adjustment needed to the BOB for vapour pressure
- c. It may be possible to simply add more ethanol to the current BOB subject to the overall formulation still being within the specification
- d. An octane saving in the BOB is possible if 10% rather than 5% ethanol is to be added. The E10 compliant BOB would have a lower required octane than for an E5 compliant BOB, allowing lower cost petroleum components to be used in the base blend
- e. Refiners who supply Ireland currently are already supplying different export markets, including E10 markets, with different finished grades/specification and so are used to blending to multiple export grades (see Section 4.2).

4.2. Supply and Logistical Issues

63. Gasoline is transported via pipeline, sea going vessels, barges and rail cars as BOB, prior to the addition of ethanol. The final distribution stage is made by road truck to retail sites, with the ethanol added at the road loading rack. The generic supply chain for gasoline, typical in Europe, is shown in Figure 9.



Source: PDC

Note: Not all permutations are shown. Modes of despatch of products can vary between refineries

64. Ireland has no product pipelines and so is dependent on product tankers to deliver product to various ports, either from the Whitegate refinery or from the UK and other European suppliers. A limited amount of gasoline is delivered inland directly from Whitegate refinery via road truck but this serves the relatively small local market in southern Ireland. There are product terminals in elsewhere in Ireland in Dublin, Galway, Foynes and New Ross and these are supplied by sea and are close to most of the major gasoline demand centres in Ireland. Onwards supply is via road truck to retail sites.
65. The overall supply chain for gasoline in Ireland operates as follows:
- a. Finished gasoline is delivered from Whitegate refinery by road truck with ethanol added at the road loading rack to make an E5 grade for final delivery to service stations;

- b. E5 compliant BOB is loaded on to vessels at Whitegate for transportation to other Irish ports where it is discharged to a receiving terminal. Ethanol is added at the road loading rack to make an E5 grade for final delivery to service stations;
 - c. Other gasoline blends and/or components are exported from Whitegate, primarily to the US (up to 250 thousand tonnes per year);
 - d. E5 compliant BOB is loaded on to vessels at UK refineries and terminals for transportation to Dublin and other Irish ports where it is discharged to a receiving terminal. Ethanol is added at the road loading rack to make an E5 grade for final delivery to service stations;
 - e. Some E5 compliant BOB (around 10-30% of imports or approximately 100-200 thousand tonnes per year) is loaded on to vessels at other European refineries and terminals for transportation to Dublin and other Irish ports where it is discharged to a receiving terminal. Ethanol is added at the road loading rack to make an E5 grade for final delivery to service stations;
 - f. Some other gasoline components and blends are exported back to the UK (typically 50-200 thousand tonnes per year) and other European markets (typically 10-50 thousand tonnes per year, usually to product trading hub located across Amsterdam, Rotterdam and Antwerp (“ARA” ports¹⁸)).
66. An illustrative and simplified view of the supply chain for gasoline to Ireland is shown in Figure 10.

¹⁸ ARA is the major European oil trading hub where there are high levels of imports and exports allowing market imbalances to be addressed, cargo consolidation (make-bulk), breaking of large cargoes into smaller ones (break-bulk), blending and other operations. The level of trade means that ARA is a pricing point and many trades are done relative to published ARA price quotations

Figure 10 Gasoline Supply Chain to Ireland



Source: PDC, UKPIA, Marinetransport.com

Note: Only some indicative shipping routes shown. All terminals in Ireland and Northern Ireland are served by sea, mostly from Whitegate refinery and UK refineries. Only UK product pipeline shown in Finnart line from Grangemouth refinery. Other pipelines are not shown for clarity.

67. The gasoline imports to Ireland are largely from coastal refineries and terminals in the west of the UK. It is interesting to note that the sea distances and sailing times from locations in the west of the UK to Dublin are shorter or at least comparable with the distance from Whitegate to Dublin. Example sea distances and sailing are shown in Table 3.

Table 3 Sea Distances and Sailing Times for Gasoline Imports to Ireland

Port of Origin	Destination Port	Distance (Nm)	Sailing Time (hrs)
Eastham, England	Dublin, Ireland	123	10
Pembroke, Wales	Dublin, Ireland	138	12
Finnart, Scotland	Dublin, Ireland	175	15
Whitegate, Ireland	Dublin, Ireland	161	13

Source: <https://sea-distances.org/>

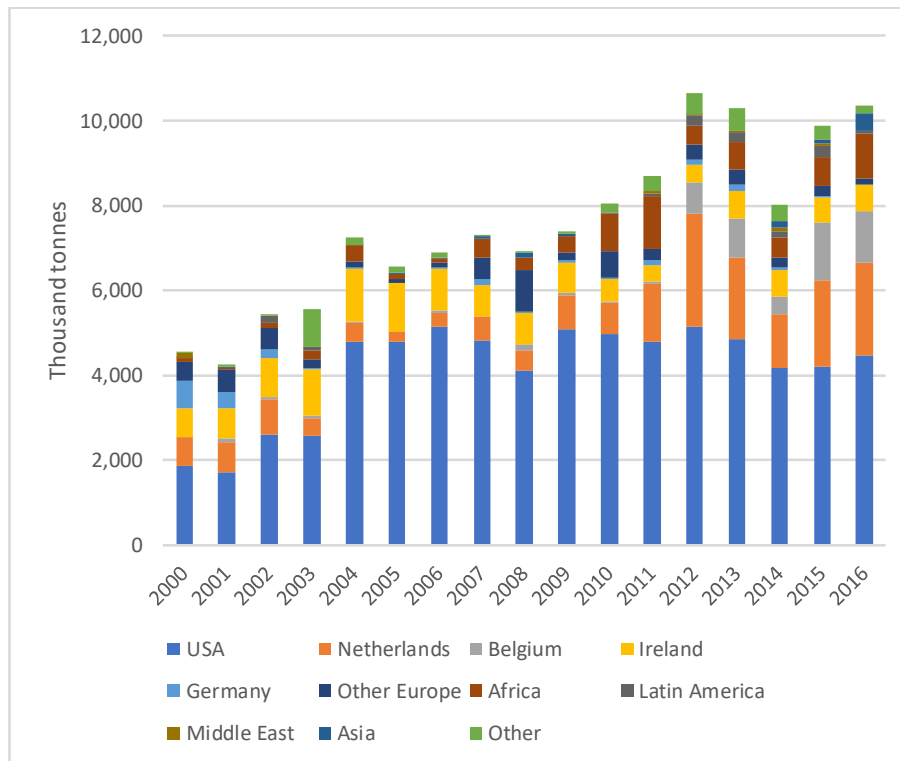
Note: Sailing times based on an average speed of 12 knots. Does not allow for casting off, coming alongside, demurrage or other factors impacting overall deliver times

68. The ports of origin have been chosen as representative of likely locations for loading of gasoline cargoes destined for Ireland. Eastham is a port close to Essar’s Stanlow refinery. Pembroke is the location of the Valero refinery in west Wales. Finnart is the location of an export terminal on the west coast of Scotland that is linked by product pipeline to the Ineos refinery in Grangemouth. The proximity of the UK ports to the major gasoline demand centre of Dublin indicates that supply from such locations is likely to be highly competitive with supply from the Whitegate refinery. In all cases cargoes would be delivered within one day.

69. As shown in Figure 4, the UK is not the only supplier of gasoline to Ireland. Some supply has also come, at various times, from Sweden, Netherlands, Belgium, Spain, France and other European countries. Supplies from the Netherlands and Belgium were from the major oil product trading hubs in ARA. Consideration has also been given to the position of UK refiners and their need to secure export markets for surplus gasoline. This surplus is currently around 4-5 million tonnes per year and around 10-15% of this surplus has been exported to Ireland.

70. The historical breakdown of gasoline exports from the UK shows how varied the end markets are. Gasoline traders and refiners in the UK manage multiple export grades, either as finished gasoline or as BOB. Figure 11 summarises this.

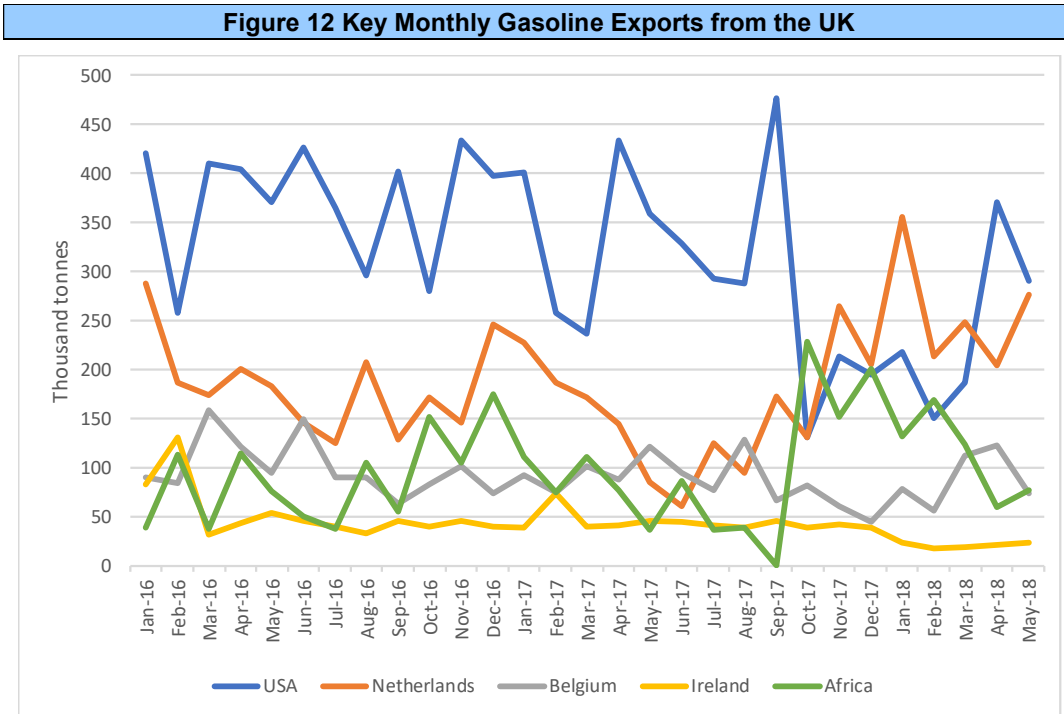
Figure 11 UK Gasoline Exports by Destination



Source: Eurostat

71. The US has had a structural deficit in gasoline that is largely met through imports from Europe with the UK being one of the major exporters to the US. Such exports make up almost half of the total gasoline exports. However, the US has become more self-sufficient in recent years due to:
 - a. Higher production from domestic refineries
 - b. Increase use of ethanol (E10 is now the standard gasoline grade)
 - c. A mature market with increased fuel efficiency leading to falling demand for refinery-sourced gasoline
72. Further, there is a seasonal element to US gasoline imports as there is a distinct “driving season” where by demand is higher in summer months than in winter months. This leads to strengthening of US prices compared to those in Europe creating an arbitrage between the two markets. This encourages UK and other European refiners to export more to the US as they achieve a better price for those exports than for more local export sales.

73. The monthly changes in key gasoline export volumes from the UK are shown in Figure 12.



Source: Eurostat
 Note: For non-bio gasoline

74. This chart shows that the US remains the main market for UK gasoline exports but these are volatile, driven by seasonality and other US specific factors such as refinery production, weather interruptions (e.g. the hurricane season). This trade is as US E10 compliant BOB (as much as 5 million tonnes per annum). It also shows that the UK trades away a significant amount of its surplus through the trading hub in ARA (shown by the exports to the Netherlands and Belgium). This is in the form of European E5 compliant BOB and as gasoline components.

75. The chart also illustrates how UK refiners and traders are willing to blend to and store on a segregated basis multiple grades; not only the different BOB grades but also ethanol-free grades of gasoline for export to African countries. These are mostly to West Africa and to Nigeria in particular. The quality required in these markets is lower than for Europe and refiners and traders will “blend down” to local specifications to maximise the profit margins on these exports.

76. UK exports to Ireland have been falling in the past few years. They now make up around 5% of UK gasoline exports, down from a pre-2008 level of almost 20%. This is partly due to falling import requirements in Ireland but also due to the level of total UK gasoline exports increasing substantially. Overall this indicates that the UK is still very well placed to supply Ireland with gasoline but these exports form part of an increasingly diverse export pattern. What UK refiners and traders have been able to demonstrate is that they can blend cargoes (as BOB or finished ethanol-free gasoline) for very different markets.

77. Other countries have also demonstrated a willingness to export to Ireland. Such exports come from countries that have already introduced higher ethanol content gasoline. This is discussed further in Section 0. Refiners, using refinery blending and tankage, and gasoline traders using rented tankage, are able to deal with multiple gasoline grades. The pattern of exports combined with the different gasoline grades emerging in Europe strongly indicates that the relatively modest level of imports to Ireland could be secured as E10 compliant BOB if the Irish market was to move to that grade.

5. Ethanol and gasoline pricing

78. Ethanol, BOB and gasoline are all commodities that are freely traded and have price quotations available via different reporting companies. ICIS¹⁹ recent published European prices for ethanol and gasoline are shown in Figure 13.

Figure 13 Recent European Ethanol and Gasoline Prices



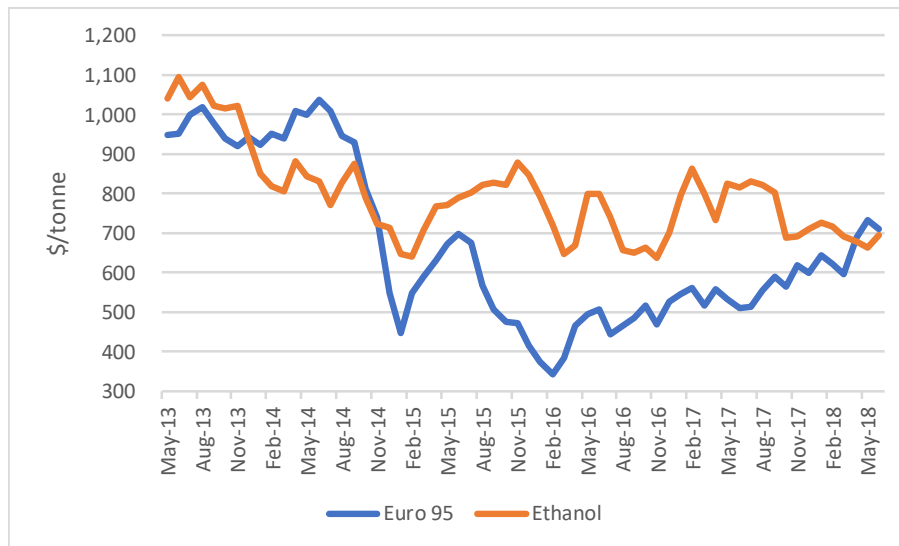
Source: ICIS

Note: Gasoline Eurobob is ethanol-free gasoline base blend traded in Europe

¹⁹ ICIS, a major petrochemical market price and information provider

79. Further analysis of data from Platts and Argus²⁰, over a longer period, shows the same trend in prices. This is shown in Figure 14.

Figure 14 Historical Trend in European Ethanol and Gasoline Prices



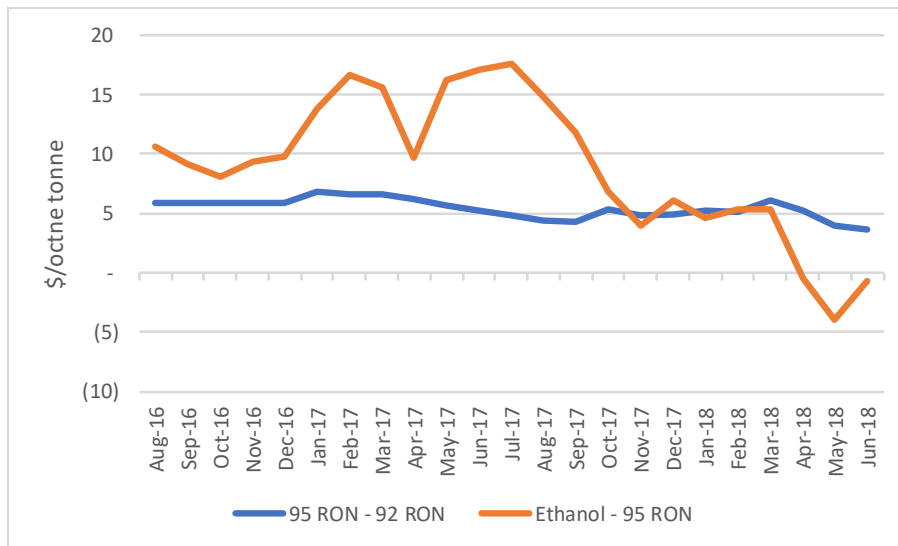
Source: Platts, Argus

80. Both sets of data, the first in € per cubic metre (€/cbm) and the second in US \$ per tonne (\$/tonne) show how the price of gasoline in Europe converged with that of ethanol. Further, Figure 14 shows that there was a period in 2014 and in early 2018 when ethanol was priced below gasoline. Given that ethanol provides additional octane to the gasoline blend, allowing the balance of the blend to be made from even lower octane, such pricing provides a strong incentive for a gasoline blender to maximise the use of ethanol.
81. By comparing the European price of the standard 95 octane gasoline and that for the regular 92 octane grade, it is possible to track the apparent value of octane in the blend. The price difference divided by the octane difference (3 octane points) gives a value for octane in US \$ per octane tonne (\$/octane tonne). A similar analysis can be applied to the difference in price and blend octane for standard 95 octane gasoline and ethanol. In this case the price difference is divided by the octane difference between 113 for ethanol and 95 for gasoline i.e. 18 octane points. Again, this gives a value for octane in US \$ per octane tonne (\$/octane tonne).

²⁰ S & P Global Platts and Argus Media are leading providers of information and benchmark prices in the oil and energy sectors

82. It is usual that higher octane components to be more highly valued, and this is reflected in a price for the standard 95 octane gasoline that is almost always higher than that for 92 octane regular grade gasoline. Producing higher octane components on a refinery tends to be costlier, involving more processing and higher operating costs. The results of this analysis of monthly octane value over the last two years are shown in Figure 15.

Figure 15 Recent Octane Values



Source: Platts, Argus, PDC assessments

83. The value of higher octane has fallen to the same level as or, most recently, below that for octane around the specification for finished products. The premium normally paid for very high-octane blend components has disappeared. This reflects the availability of components with different octane blending values; a high level of ethanol availability or, in other words, a perceived surplus, will push ethanol prices down until demand picks up. The market forces that act on gasoline and ethanol prices are not directly linked and so convergence and divergence of price will happen over time.
84. Calculating the difference in production cost for E10 and E5 gasolines will vary refinery to refinery and is difficult to determine as refineries do not simply make one product but a range of products. So, a refiner may optimise, say, diesel production at the expense of gasoline production because overall it is the most profitable way to operate. However, the value of an E5 compliant BOB and E10 compliant BOB can be estimated by discounting the price from the 95 RON gasoline price by the value per octane tonne multiplied by the number of octane points below 95 that each BOB will have.

85. Octane does not blend linearly. Hence refiners have developed Octane Blending Numbers that do blend linearly to more easily allow prediction of the octane of finished gasoline blends. Such blending numbers represent the octane value of a component in a blend rather than as a separate pure component. These can be developed through experience or through calculation based on complex formula that can be derived through extensive laboratory research. As shown in Figure 6 and Table 2, the blending RON for ethanol is 113-116. A conservative approach to considering the uplift to RON in a blend provided by ethanol would be to use the 113 value. A calculation of the RON for blends of E5 and E10 gasoline is shown in Table 4:

Table 4 Octane of E5 and E10 Gasoline Blend		
Product	Blending RON	Comments
E5 compliant BOB	94.8	Made to ensure a small manufacturing margin when 5% ethanol added
E10 compliant BOB	93.8	Made to ensure a small manufacturing margin when 10% ethanol added
Ethanol	113.0	Lower value in the reported Blending RON value range
E5 EN228 Gasoline	95.7	Likely final blend RON from a 95%/5% BOB/ethanol blend i.e. slightly above the minimum EN228 specification of 95.0
E10 EN228 Gasoline	95.7	Likely final blend RON from a 90%/10% BOB/ethanol blend i.e. slightly above the minimum EN228 specification of 95.0

Note: Other adjustments may need to be made for other qualities/specifications. Octane of finished blend is above the legal specification but needs to reflect the repeatability (same operator/same laboratory) of 0.2 RON, and a reproducibility (different operators in different laboratories) of 0.7 RON in the relevant test methods (ISO 5164 or ASTM D2699)

86. Assuming such blends (95%/5% BOB/ethanol volume-based blend for E5 gasoline and 90%/10% BOB/ethanol volume-based blend for E10 gasoline), the incremental cost of production has been assessed for the last 3-4 years. This is summarised in Table 5, converted back to a \$ per tonne basis, and in Figure 16.

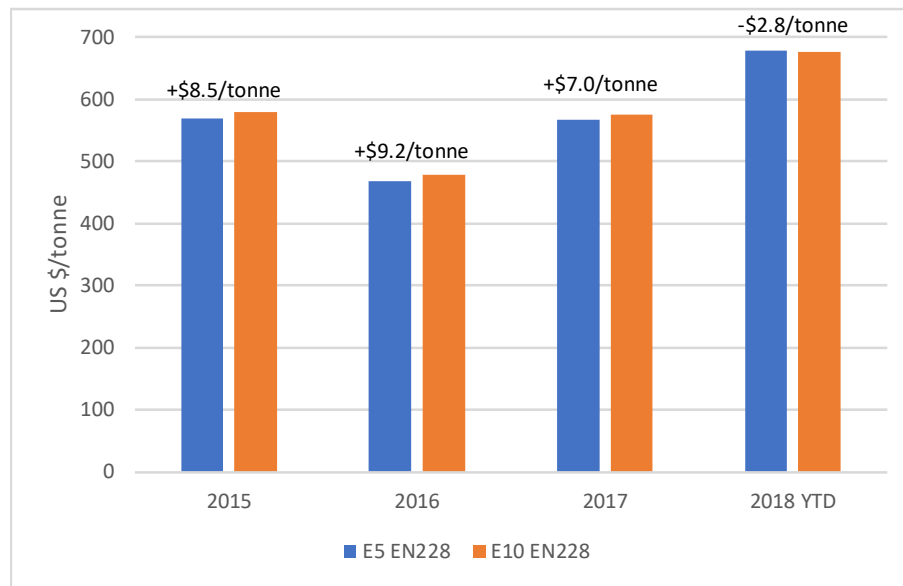
Table 5 Incremental Production Costs for E10 versus E5

	E5 BOB \$/tonne	E10 BOB \$/tonne	Ethanol \$/tonne	E5 EN228 \$/tonne	E10 EN228 \$/tonne	Difference \$/tonne	Difference %
2015	558.2	554.9	777.7	569.7	578.2	8.5	1.5%
2016	455.4	451.1	706.3	468.6	477.8	9.2	1.9%
2017	555.0	549.5	782.4	566.9	573.9	7.0	1.2%
2018 YTD	676.7	672.1	701.8	678.0	675.2	-2.8	-0.4%

Source: Platts, Argus, PDC assessments

Note: Blend calculated on a volume basis and converted back to mass (\$/tonne) basis

Figure 16 Assessed Gasoline Values for E5 and E10 Grades



Source: Platts, Argus, PDC assessments

Note: Blend calculated on a volume basis and converted back to mass (\$/tonne) basis

87. What the current relative pricing of gasoline and ethanol means is that there is little or no additional cost of using an increased amount of ethanol, as would be needed if making E10 gasoline rather than E5 gasoline.

6. Ethanol in gasoline in other markets

88. There is already an established market for E10 gasoline in several European countries and it is now the standard fuel in the US. The market share for E10 in various markets is show in Table 6.

Table 6 E10 Market in Various Countries

Country	E10 Market Share	Comments
US	95%+	Market almost entirely E10 but has a lower octane than European grades. E15 and E85 grades also available
Belgium	78.5%	For 2017. E10 now the main 95 RON grade. A separate 97 RON E5 grade also available. Belgium has a 2- gasoline grade supply chain, as in part seen in the UK
Finland	68%	As at 2017. Introduced in 2011, uptake varied with pricing and public perceptions
France	41.4%	As at June 2018. 95 RON E10 now the main grade. 98 and 95 RON E5 grades also available
Germany	12.6%	As at 2016. Uptake slow due to public perceptions. No government tax incentives

Source: EIA, S&P Global Platts, BDBe, www.e10bensini.fi, Low Carbon Vehicle Partnership, www.epure.org, Fédération pétrolière Belge

89. Table 6 shows that there are already significant markets for E10 gasoline in Europe. Much of this is supplied directly from domestic refineries. This means that the refineries in France, Germany, Finland, and Belgium are all capable of making E10 compliant BOB. Such E10 compliant BOB could readily be exported to Ireland. Import data for Ireland shows that France and Belgium have historically been suppliers. Recent vessel movements and import statistics indicate oil product tankers delivering cargoes from France, Belgium, Netherlands, Spain and Scandinavian countries.²¹
90. However, the UK is still the major supplier of gasoline imports to Ireland, but UK refineries do not currently make an E10 BOB fully compliant with E10 EN228 gasoline. So, the key question is, what would these UK refiners and others do if Ireland were to move to E10 gasoline?

²¹ <https://www.marinetraffic.com/>, Eurostat

91. Given the pattern of UK gasoline exports to multiple markets, plus the production of E10 BOB elsewhere in Europe, it is highly likely that

- a. Ireland can source all its E10 BOB import requirements from France or Belgium if required
- b. UK refiners would need to export surplus gasoline to more distant markets if they forego supply to Ireland
- c. UK refiners already make multiple export gasoline and BOB grades and have sufficient tankage, on site or in product terminals, to make export cargoes to differing standards
- d. UK refiners would most likely make the economic decision to adjust the quality of BOB exports to Ireland to ensure they continue to capture these rather than allow these to be source from continental Europe
- e. Whitegate refinery would adjust its gasoline production to make E10 BOB for distribution by vessel or barge direct from the refinery to other Irish ports and to provide finished E10 gasoline via road truck to the local market area.

Conclusions

The introduction of gasoline with up to 10% ethanol content (an “E10” grade), replacing the current grade which has up to 5% ethanol (“E5” grade), is a logical way to move towards meeting the proposed new biofuels blending target in Ireland.

Gasoline demand in Ireland has been declining and this trend is likely to continue. Hence the level of imports required may also fall but this also depends on the level of continuing supply from Whitegate refinery into the Irish market.

The gasoline market in Ireland can continue to be supplied through production at the Whitegate refinery and imports from the UK or other European countries. Other import sources have been France, Netherlands, Belgium, Spain and Scandinavia and many of these countries are already producing and consuming E10 gasoline.

The existing supply chain for the Irish gasoline market can manage a switch from E5 to E10. Imports can continue as a blend stock for oxygenate blending or “BOB” with ethanol added to ethanol-free gasoline blends at a late stage in the supply chain, usually on the road loading rack where road trucks are filled for final delivery to retail sites.

The addition of ethanol to a BOB changes various fuel qualities including the octane, vapour pressure and density. The final blend must meet all the EN228 specification for gasoline in Europe hence it is important that the BOB is formulated to be appropriate for the addition of the desired amount of ethanol. Hence an optimised E5 compliant BOB will be slightly different from an optimised E10 compliant BOB.

It may be possible to simply add more ethanol to the current BOB subject to the overall formulation still being within the specification and this would need verification with the source refiner or through careful testing. An octane saving in the BOB is possible if 10% rather than 5% ethanol is to be added. The optimised E10 compliant BOB would have a lower required octane than for an optimised E5 compliant BOB, allowing lower cost petroleum components to be used in the base blend.

European refineries are already producing different gasoline blends and BOBs for different export markets as well as for their domestic markets where E5 and E10 gasoline grades are simultaneously available. The UK, historically the major source of supplies for the Irish market, is also a significant exporter of gasoline to the US where the market is almost entirely E10 grade.

Refiners in the UK and other European countries are already in a position to supply the Irish market with appropriate gasoline blends to make an E10 finished gasoline with up to 10% ethanol being added prior to road truck loading in Ireland.

Recent pricing of gasoline and ethanol indicates that there is little or no additional cost of using an increased amount of ethanol, as would be needed if making E10 gasoline rather than E5 gasoline.

Current production of E10 BOB in Europe and the existing pattern of gasoline blend exports means:

- Ireland can source all its E10 BOB import requirements from France or Belgium if required
- UK refiners would most likely make the economic decision to adjust the quality of BOB exports to Ireland to ensure they continue to capture these rather than allow them to be sourced from continental Europe
- Whitegate refinery would adjust its gasoline production to make E10 BOB for distribution by vessel or barge direct from the refinery to other Irish ports and to provide finished E10 gasoline via road truck to the local market area

If Ireland were to change to requiring E10 gasoline instead of the E5 grade, it would be following the change already in progress in several other European countries.