Asia-Pacific
Economic Cooperation

Roadmap for Increasing the Production, Use, and Trade of Ethanol as a Transport Fuel in the APEC Region

Energy Working Group

March 2017

APEC Project: EWG 12 2015A

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APEC#217-RE-03.2

Abbreviations & Acronyms

Roadmap:

APEC	Asia-Pacific Economic Cooperation
bbl.	Barrel
BOB	Blendstock for Oxygenate Blending
CARB	California Air Resources Board
CBI	Caribbean Basin Initiative
CI	Carbon Intensity
CIDE	Contribution for Intervention in Economic Domain
CO_2	Carbon Dioxide
DDGs	Distillers Dried Grains
DEVIDA	Alternative Development Agency
DOE	Department of Energy
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
FFV's	Flex-Fuel Vehicles
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IEA	International Energy Agency
LCA	Life Cycle Analysis
LCFS	California's Low Carbon Fuel Standard
MFN	Most Favored Nation
MJ	Megajoule
MTBE	Methyl Tert-Butyl Ether
MVO	Dutch Oils and Fats Association
NOx	Oxides of Nitrogen
ORNL	Oak Ridge National Laboratory
PM	Particulate Matter
PROINVERSION	Peru's Investment Agency
RED	Renewable Energy Directive
RFA	Renewable Fuels Association
RFG	Reformulated Gasoline
RFS	Renewable Fuel Standard
RINs	Renewable Identification Numbers
RON	Research Octane Number
RVP	Reid Vapor Pressure
SRA	Sugar Regulatory Association
USD	US dollar or US$
USDA	U.S. Department of Agriculture
VEETC	Volumetric Ethanol Excise Tax Credit
VOC's	Volatile Organic Compounds

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Roadmap for Increasing Ethanol Blending

Introduction

The objective of this report is to develop a roadmap that highlights the steps for implementing a domestic ethanol program. The idea for a roadmap originated at the APEC workshop in Taichung City, Chinese Taipei on the 12th-13th of April, 2016. During the workshop, the 14 participating economies, represented by biofuel associations, government representatives, and international experts, shared their individual experiences, successes, and challenges in developing a domestic ethanol industry. At the conclusion of the workshop the participants identified critical factors that contribute to a successful ethanol industry that were common among the more successful experiences.

At the conclusion of the workshop, the participating economies agreed that in accordance with the 2015 Energy Ministerial Cebu Declaration encouraging member economies to "cooperate on best practices;" "exchange information;" and "work toward achieving greater energy security, reduce carbon emissions, and promote trade and investment" that they would develop a road map for increasing the sustainable and financially viable production, use and trade of ethanol in order to meet the goals of the Cebu Declaration. This roadmap draws on the experiences of the 14 participating economies, international organizations, and industry leaders to summarize the key elements of a successful ethanol program.

The roadmap is divided into two parts. In the first part, we outline the many and diverse benefits of fuel ethanol upon the environment and economy drawing upon the featured case studies. The second part examines the different policy tools that have been employed to stimulate the demand and supply of fuel ethanol. We consider the pros and cons of each type of policy tool and conclude by offering policy recommendations to a fledgling fuel ethanol program. The policy analysis draws not only upon the case studies, but on the experience of Brazil and Europe, whose fuel ethanol markets are well developed.

The benefits of fuel ethanol

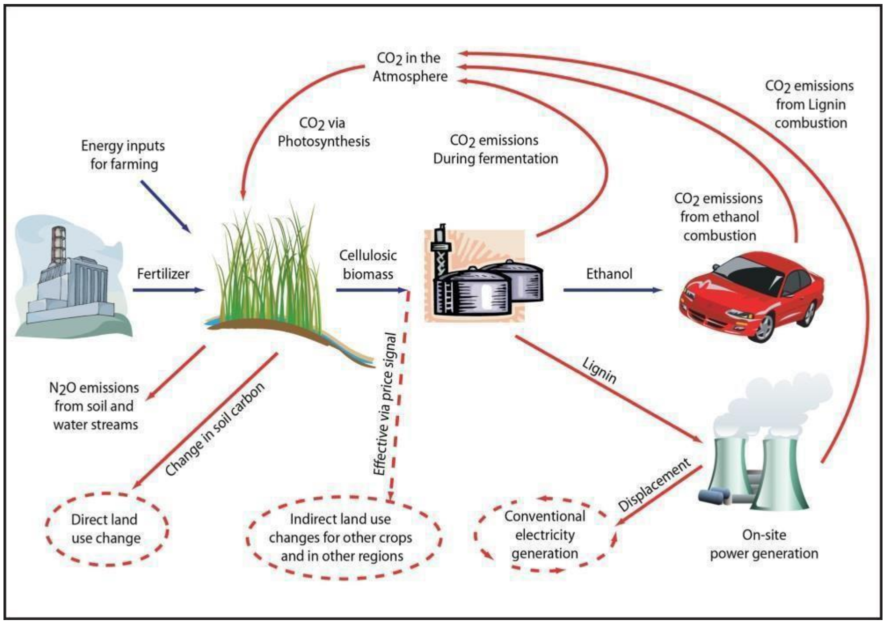
Fuel ethanol has a beneficial impact on the environment, rural and industrial economic sectors as well as diversifying the transport fuel pool. This section outlines the main benefits which include:

- Climate change mitigation
- A renewable alternative to fossil fuels
- Improvements to air and water quality
- Economic benefits
- Improved energy security and diversification
- Improvements in fuel quality

Climate change mitigation

Ethanol has the potential to reduce greenhouse gas (GHG) emissions when it is utilized as a component of gasoline in transport. The reduction in emissions occurs because carbon dioxide is removed from the atmosphere by photosynthesis when the feedstock for ethanol is grown (Diagram 1.1). This is not the case when crude oil is extracted from the ground. As for gasoline, carbon dioxide and other gases are released back into the atmosphere when ethanol is combusted in transport. The extent to which a biofuel reduces GHG emissions relative to its fossil counterpart depends on the feedstock and processing technology used.

Diagram 1.1: The life cycle of biofuels



Many biofuel policies state that ethanol must generate specified levels of greenhouse gas savings if they are to qualify for mandates. For example in the U.S., the Renewable Fuel Standard (RFS) requires that conventional biofuels (corn ethanol) must reduce GHG emissions by a minimum of 20%. Advanced biofuels (i.e. sugarcane ethanol) must reduce GHG emissions by 50% while cellulosic biofuels must reduce emissions by 60%. California's Low Carbon Fuel Standard (LCFS) requires that the state reduce the carbon intensity (CI) of fuel by 10% in 2020 relative to 2010. In Japan, fuel ethanol must generate GHG savings of 50% to qualify as a biofuel.

Under the EU's revised Renewable Energy Directive (RED) published in September 2015, biofuels must generate GHG savings of at least 60% for biofuels produced in plants starting operations after October 2015. For plants in operation before then, plants must achieve GHG savings of at least 35% until the end of 2017 and at least 50% from January 2018.

In Brazil a lifecycle analysis of sugarcane ethanol published in 2011 by Seabra, J. et al. calculated emissions of 21.3g CO_2eq/MJ. That is equivalent to a reduction of 80% compared to conventional gasoline.

GHG emissions for various fuels are determined by using a life cycle analysis (LCA). This measures the carbon intensity of a fuel in grams of GHGs (carbon dioxide, methane, and nitrous oxide). Life cycle analysis is also referred to as a "well-to-wheels" analysis reflecting the fact that it analyzes the GHG emissions associated with each step in the process of producing and consuming fuels. Such analyzes are complicated and several different methodologies have been developed, each of which gives slightly different results. A key area of contention is how to treat the emissions associated with the various co-products of ethanol. For this reason, the results of different LCA studies may not be comparable.

Diagrams 1.2 and 1.3 present the results of life cycle analyzes carried out by Argonne National Laboratory using their GREET model (April 2016). Diagram 1.2 reveals that while gasoline has emissions of over 90g CO_2 eq/MJ, ethanol has lower emissions ranging from just below zero to 60g CO_2 eq/MJ depending on the feedstock. Ethanol reduces GHG emissions relative to gasoline by an average of 34-104% including indirect land use change (Diagram 1.3). Ethanol produced from biomass has higher GHG savings than ethanol produced from crops because the lignin from biomass can be burned to provide energy for the factory, thereby reducing the plant's reliance on fossil energy (Diagram 1.1).

Increasing efficiency in ethanol production reduces energy consumption and this leads to a reduction in the GHG emissions from the production process. Ongoing reductions in fertilizer use and increasing feedstock yields have a similarly positive effect. We therefore expect the GHG emission reductions of ethanol relative to gasoline to continue to improve.

Diagram 1.2: Life-cycle GHG emissions of Selected biofuels

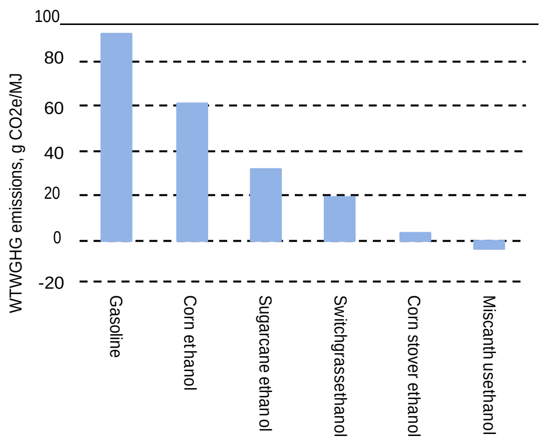
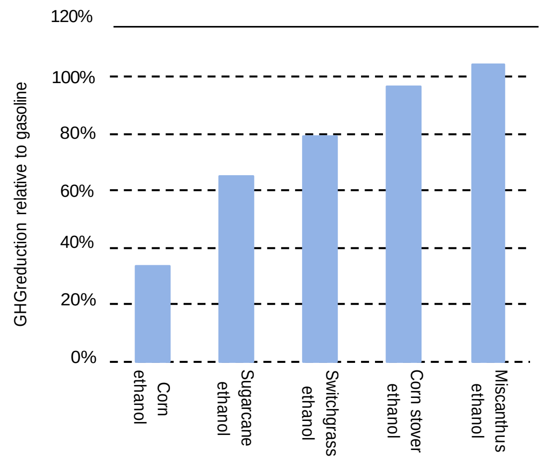


Diagram 1.3: Reduction in GHG emissions by ethanol relative to gasoline



A study by Illinois University[1] examined the GHG savings of corn ethanol produced under different co-product, yield and energy consumption scenarios. The study was conducted using Japanese gasoline as a baseline which has a lower level of emissions (just over 80g/MJ) than those used in the GREET model. The scenarios were as follows:

- Base corn ethanol - DDG sold dry, corn oil extracted for biodiesel production, displacing diesel
- High efficiency - as per the base case but DDG is sold wet and some efficiency gains are assumed (-10% natural gas, +3% yields, -3% power consumption)
- DDG CO_2 bottling - as per the base case but the CO_2 is captured for food and beverage use
- DDG CO_2 EOR - the CO_2 is captured for food and beverage use and there is enhanced oil recovery
- Digester - as per the base case but there is anaerobic digestion of the syrup, DDG and manure

The results are summarized in Diagrams 1.4 and 1.5. All of the corn ethanol scenarios apart from the base case meet the 50% GHG reduction requirement for Japanese ethanol. The scenarios with CO_2 bottling result in higher GHG savings for corn ethanol than for Brazilian sugarcane ethanol.

[1] *Greenhouse Gas Life Cycle Analysis of U.S.-Produced Corn Ethanol for Export to Global Markets* (2015) for the U.S. Grains Council by Mueller & Unnasch at the University of Illinois at Chicago Energy Resources

Diagram 1.4: Life-cycle GHG emissions of corn ethanol

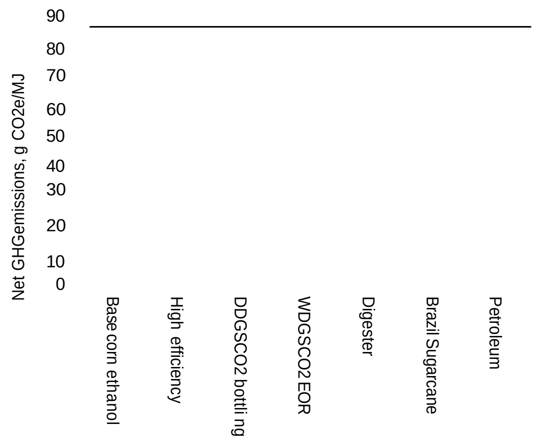
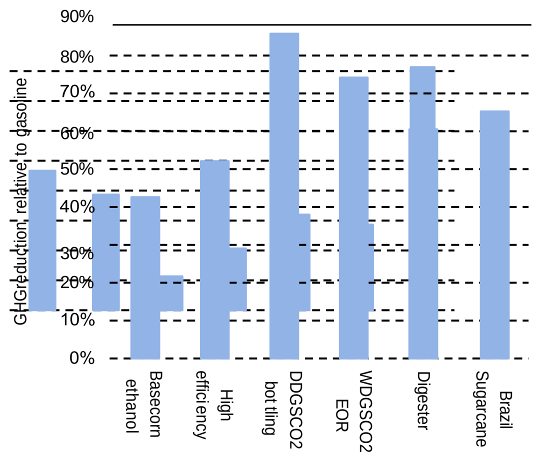


Diagram 1.5: Reduction in GHG emissions by relative to gasoline



A renewable alternative to fossil fuels

Ethanol reduces an economy's dependence on finite fossil fuels and offers a renewable alternative. The energy balance of ethanol is positive in that it contains more energy than it requires in its production. Research into the energy balance of ethanol reveals that the balance depends mainly on the feedstock and process employed. As per the GHG savings, the energy balance is improving over time as ethanol production becomes more efficient.

A recent study by the U.S. Department of Agriculture (USDA) published in February 2016[2] found that the energy balance of corn ethanol ranged from 2.1 to 2.3, assuming the distillers dried grains (DDGs) by-product is dried and the energy is purchased. This means that corn ethanol contains over twice the fossil energy required in its production. If the DDGs can be sold wet then the energy balance rises to 4.

Other studies show a positive energy balance for ethanol produced from other feedstocks including sugar cane, molasses, and wheat. For example, a study on Brazilian sugarcane ethanol found that it contains 9.3 times the energy inputs required in its production[3].

Improved air and water quality

Poor air quality is a major threat to human health. For example in the EU, 17 of the 25 states were found to be in breach of their air quality targets. Ethanol can make an important contribution to meeting air quality standards. The burning of gasoline in car engines generates tail pipe emissions which are subject to regulation. These undesirable pollutants include:

- Carbon monoxide - a toxic compound that reduces the blood's ability to carry oxygen in tissues and is associated with a number of adverse health effects particularly in people with cardio vascular disease.

- Hydrocarbons - contribute to ground level ozone and in some cases are known to have adverse impacts on human health.

[2] Gallgher, Yee, & Baumes (2016) *2015 Energy Balance for the Corn-Ethanol Industry* for the United States Department of Agriculture (USDA)

[3] *A Sustainability Analysis of the Brazilian Ethanol* (2008) for UK Embassy Brasilia and DEFRA by Walter *et al.* at the University of Campina

- Oxides of Nitrogen (NOx) – are linked to respiratory illnesses.
- Particulate Matter (PM) – formed from soot produced during combustion.
- Toxic pollutants including benzene, butadiene, acetaldehyde, formaldehyde and polycyclic aromatic compounds many of which cause cancer and other health problems.

As ethanol is a high octane fuel, it allows the engine to more completely combust the fuel, resulting in fewer emissions. Ethanol does not contain olefins, aromatics or sulfur (although ethanol denaturants may contain these components). These are all present in gasoline and diesel and are known to have negative impacts on air quality. A number of studies have been carried out into the effects of low and high level ethanol blends on tail pipe emissions. The International Energy Agency[4] reviewed studies on air quality impacts of E-10 blends and found that E10 reduced emissions of carbon monoxide, exhaust volatile organic compounds (VOC's), particulate matter and some unregulated pollutants. In its review of the impact of ethanol blending on air pollution, the IEA concluded:

"The net benefits could be substantial, particularly from PM reduction in cities with high average tailpipe emissions, such as in many developing economies."

In the U.S., ethanol makes a significant contribution to air and water quality. Legislation under the Clean Air Act administered by the U.S. Environmental Protection Agency (EPA) is responsible for controlling air quality. The EPA has set air quality standards for six common pollutants: particulate matter, ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, and lead. The transport sector is a key potential source of emissions affecting air quality.

Table 1.1: The health benefits of ethanol as an oxygenate

Air Toxins	-20%
Volatile Organic Compounds	-17%
Nitrogen Oxides	-3%
Carbon Monoxide	-13%
Sulfur Oxides	-11%
Carbon Dioxide	-4%
Particular Matter	-9%
Reduced Cancer Risk	-20-30%

Source: Clean Fuels Development Coalition Technical Committee, California Air Resources Board.

The 1990 Clean Air Act amendments established new auto gasoline reformulation requirements, set Reid Vapor Pressure (RVP) standards to control evaporative emissions from gasoline, and mandated new gasoline formulations sold from May to September in many states. Specifically, the act required reformulated gasoline (RFG) to contain 2% oxygen by weight. Initially, MTBE was used as an oxygenate, but in 2000, environmental and health concerns led the EPA to draft plans to phase out its use nationwide. From the beginning of 2004, California banned MTBE, and by 2006, 25 states had signed legislation to ban its use. MTBE was replaced by ethanol as an oxygenate. Now almost all gasoline sold in the U.S. contains 10% ethanol. The oxygenate rule has now been superseded by the Renewable Fuels Standard, which is also part of the EPA's strategy for meeting the requirements of the Clean Air Act.

[4] *Biofuels for Transport*, an International Perspective (2004) by the International Energy Agency

According to scientific research, ethanol in reformulated gasoline has a number of health benefits, including a reduction in air toxins, volatile organic compounds (a key source of ozone) and a reduction in cancer risk (Table 1.1).

Economic benefits

Many studies have been carried out demonstrating that ethanol makes a substantial contribution to the national economy. As agricultural raw materials form the main component of ethanol production costs, ethanol industries provide a major source of support for agriculture. Ethanol helps to support crop prices and farm incomes at a higher level than would otherwise be the case. In addition, renewable fuels are a major engine for research and development in the public and private sectors. The spending associated with ethanol production and R&D circulates and re-circulates throughout the entire economy stimulating aggregate demand and supporting jobs and household income.

Most economic impact studies have focused on Europe, Brazil and the U.S. According to a 2012 report published by the Dutch oils and fats association (MVO)[5], the renewable ethanol industry generated and sustained 70,000 direct and indirect jobs in Europe during the economic crisis. By 2020, based on current growth projections, employment in the European sector could reach up to 250,000 jobs[6]. In France in 2010, the ethanol industry sustained 8,900 jobs and generated over €300 million (net) of direct added value for the French economy[7]. A single ethanol plant in Germany alone sustained 2,500 jobs, created €51 million of direct added value to the economy and generated indirectly an additional €96 million for other industries, such as farming[8].

Studies carried out in Brazil have found a similarly positive effect. In 2008, the sugar and ethanol industry generated wealth totaling US$28.15 billion, equivalent to almost 2% of Brazil's GDP. When taking into account total sales of the various links comprising the sugarcane industry agri-industrial production system, the value reaches US$86.8 billion. The industry provides 1.28 million jobs in the formal economy. In 2008, ethanol and sugar generated revenues of $12.5 billion and $9.8 billion respectively, with smaller contributions from electricity and chemicals[9].

In a study carried out for the renewable fuels association (RFA) by John Urbanchuk[10] and updated in 2013, the impact of ethanol on the U.S. economy was assessed by examining the backward and forward linkages between the ethanol industry and other parts of the economy. For example, ethanol refineries buy corn from the agriculture sector which in turn buys crop protection products and fertilizer from the agro-chemicals sector, which in turn purchases products from other sectors. The study distinguishes between three different types of effect (the direct, the indirect and the induced effects). The *direct* effect is the known or predicted change in the local economy, i.e., jobs and revenues created by ethanol plants. The *indirect* effect is the business-to-business transactions required to produce the direct effect, i.e., the purchase of chemicals for ethanol production. Finally the *induced* effect is derived from spending on goods and services by people working to satisfy the direct and indirect effects (i.e., increased household spending resulted from higher personal income).

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[5] *Global Economic Impact of Biofuels* (2012) for the MVO (de ketenorganisatie voor oliën en vetten)

[6] *Global Economic impact of Biofuels* (2012) for the GRFA (Global Renewable Fuels Association)

[7] *Les impacts socio-économiques de la filière bioethanol en 2010* by PricewaterhouseCoopers (2013)

[8] *The economic importance of bioethanol production* by the CropEnergies group in Germany, Research project (2013)

[9] The Sugar-Energy Map of Brazil (2011) by Neves, Trombin & Consoli

[10] Urbanchuk, J. (2013) *Contribution of the Ethanol Industry to the Economy of the United States*, for the Renewable Fuels Association

Table 1.2 summarizes the results of Urbanchuk's study. This reveals that the total contribution of ethanol to the U.S. economy was US$43.4 billion. In addition, over 380,000 jobs were created and the industry generated an income of US$30 billion (i.e., the sum of employee compensation and proprietor income). Diagram 1.6 reveals that three quarters of the economic contribution was to agriculture. Diagram 1.7 highlights that almost half of the economic contribution came through indirect impacts on related industries.

Table 1.2: Economic impact of the U.S. ethanol industry (2012)

	GDP (US$ Million)	Employment (Jobs)	Income (US$ Million)
Ethanol Production	**8,177**	**84,575**	**4,831**
Direct	783	11,971	783
Indirect	4,419	37,231	2,384
Induced	2,975	35,373	1,663
Agriculture	**32,399**	**267,605**	**23,380**
Direct	1,596	66,057	1,240
Indirect	16,347	42,172	14,061
Induced	14,455	159,376	8,080
R&D	**2,815**	**31,081**	**2,035**
Direct	967	9,264	966
Indirect	594	6,897	368
Induced	1,254	14,920	701
Total	**43,391**	**383,260**	**30,246**
Direct	3,347	87,292	2,990
Indirect	21,360	86,300	16,813
Induced	18,684	209,669	10,444

Source: Urbanchuk, J. (2013) *Contribution of the Ethanol Industry to the Economy of the United States.*

Diagram 1.6: Impact of U.S. ethanol on GDP (US$ millions)

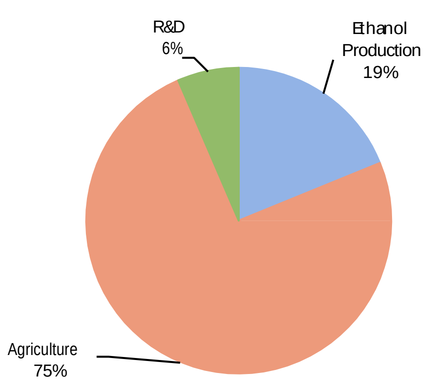
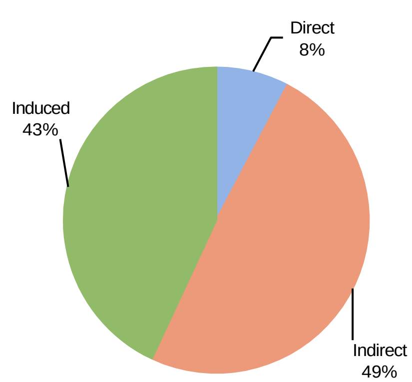


Diagram 1.7: Direct, indirect and induced contribution to GDP (US$ millions)



Improved energy security and diversification

Fuel ethanol improves energy security and reduces an economy's dependence on potentially unstable supplies of crude oil. In addition, it helps to improve an economy's trade balance and generate foreign exchange savings. Table 1.3 calculates the value of crude oil displaced by ethanol in 2015. As per the U.S. Energy Information Association (EIA), we assume that 19 gallons of gasoline are produced from a barrel of crude oil[11]. As ethanol has a lower energy content than gasoline, 1.52 gallons of ethanol are required to displace 1 gallon of gasoline. All of the economies featured in Table 1.3 were net importers of oil in 2013, except for Brazil and Canada. The table reveals that the value of oil displaced by ethanol in the U.S. was almost US$25 billion in 2015. In Brazil the introduction of ethanol mandates and supports has helped the economy switch from being a net importer of crude oil, with net imports of almost 440 million barrels in 1997, to become a net exporter by 2009.

Table 1.3: Calculation of the value of crude oil displaced by ethanol, 2015

		Brazil	Canada	Peru	Philippines	Thailand	U.S.
Ethanol consumption	(million liters)	26,801	2,820	161	509	1,302	52,911
Ethanol consumption	(million gallons)	7,080	745	42	134	344	13,978
Crude oil displaced	(million barrels)	245.2	25.8	1.5	4.7	11.9	484.0
Crude oil price	(WTI, US$/bbl.)	48.73	48.73	48.73	48.73	48.73	48.73
Value of crude oil saving	(US$ million)	11,946	1,257	72	227	580	23,585

Improved fuel quality

Ethanol has a higher octane rating than gasoline, making it a higher quality fuel. Octane is a measure of a fuel’s ability to prevent engine knock. Knock occurs when there is premature combustion of fuel in the engine cylinder. In the U.S., prior to the Clean Air Act of 1990, engine knock was reduced through the addition of lead. However, the use of lead in gasoline was phased out in the 1980s due to health concerns. Nowadays, anti-knock components are provided by ethanol and other gasoline additives.

Octane is measured in terms of its Research Octane Number (RON), or the average of RON plus the Motor Octane Number divided by two. Given pure ethanol’s high octane rating of about 113 before the addition of any denaturants, it is commonly blended into a sub-octane gasoline Blendstock for Oxygenate Blending (BOB) which has a RON of approximately 84 to 88 to produce finished gasoline with adequate knock resistance (in terms of the anti-knock index). Thus ethanol allows refiners to use cheaper, lower quality gasoline and still meet existing fuel specifications.

A study by Oak Ridge National Laboratory (ORNL) published in July 2016 found that high octane fuels in the form of mid-level ethanol blends could have significant benefits for the U.S. transport sector. The study looked at the impact of mid-level blends (up to E40) on the fuel economy of flex-fuel cars. The study found an increase in fuel efficiency of 5-10% compared to conventional cars operating on E-10. The study concluded that the higher octane rating of the fuel, the better the energy efficiency of flex fuel cars, offsetting the lower energy density of the mid blend fuels compared to E-10.

[11] Refineries in the United States produce an average of about 12 gallons of diesel fuel and 19 gallons of gasoline from one barrel (42 gallons) of crude oil. It should be noted that the calculation in Table 1.3 does not account for the value of non-gasoline outputs from a barrel of oil.

Policy tools for raising ethanol use

This section examines the various policy tools for stimulating demand and supply of ethanol. We comment on the advantages and disadvantages of each tool as well as provide examples of where policies have been particularly effective. Specifically we examine:

- Mandates and targets
- End-user incentives or penalties
- Producer incentives
- Low versus high level ethanol blends
- Administration of biofuel policies
- Biofuel trade policies

Mandates and targets

Percentage and volumetric blending mandates

Mandates and targets are the back bone of most fuel ethanol policies. Mandates are usually given as a percentage blend in gasoline (as in Canada; Peru; and the Philippines) or may be given as volumetric targets (as in Thailand and the U.S.). Unlike most economies which target consumption, Thailand has volumetric targets for production. In the U.S., the conventional mandate of the Renewable Fuels Standard (RFS) is satisfied principally with corn ethanol, with sugarcane ethanol being used in the undifferentiated category.

Mandates based on low level blends are very useful policy tools as they commit refiners to supplying gasoline containing a fixed percentage of ethanol. As ethanol is blended in relatively low proportions with gasoline such as 5% or 10%, any difference in price is usually barely noticeable at the pump by the consumer. The drawback of specifying a nationwide blending mandate is that it does not take into account geographical differences in ethanol availability. Peru dealt with this problem by rolling out the mandate gradually across different states. Canada has adopted a similar strategy by having different mandates in different provinces.

It could be argued that Thailand has been most successful in terms of boosting ethanol demand as the economy has achieved the highest rate of blending in gasoline (Table 1.4). However, as we will see below, Thailand also has the most generous subsidies available as well as comprehensive policies to boost both high and low level blends.

It is worth noting that mandates without enforcement are usually not particularly effective at stimulating demand. Traditionally oil companies have seen ethanol as a threat to their market as well as an additional cost. Any successful ethanol program therefore needs to support mandates with fiscal incentives/penalties as well as support the oil refiners in making the necessary infrastructure changes to accommodate ethanol.

Table 1.4: Ethanol mandates and targets with fulfillment rates in the featured economies

	Canada	Peru	Philippines	Thailand	U.S.
Mandate	Original aim of 5% nationwide by 2010	7.8% announced 2005, roll-out began 2010	5% from 2009	330 million liters by 2006	2005 RFS mandates 7.5 billion gallons by 2012
	Current federal mandate: 5%	7.8% nationwide from 2011 (with 5 states exempt)	10% from 2012	990 million liters by 2011	2007 EISA mandates:
	Current provincial mandates: 5 - 8.5%		Aiming for 20% from 2020	2.0 billion liters by 2016	*15 billion gallons (conventional)*
				3.3 billion liters by 2021	*16 billion gallons (cellulosic)*
Fulfillment				4.1 billion liters by 2036	*5 billion gallons (undifferentiated)*
2015 consumption (million liters)	2,820	161	509	1,223	52,911
2015 blend in gasoline	5.9%	6.7%	9.1%	12.8%	10.0%
Current mandate met?	Yes	Yes1	No	No	Yes for conventional

Note 1: Mandate met in all states in which it is applied.

Greenhouse gas reduction mandates

A new type of mandate which has been adopted in California and Germany is the GHG reduction mandate. The advantage of this approach is that it rewards biofuels according to the extent to which they reduce GHG emissions relative to their fossil counterpart.

The Californian Low Carbon Fuel Standard (LCFS) is a potentially significant driver of biofuels use (ethanol and biodiesel). California is one the largest consuming states for transport fuels in the U.S. and therefore a significant source of greenhouse gas emissions. California consumes around 17% of the total motor gasoline used in the U.S.

The aim of the LCFS is to reduce the carbon intensity of transport fuels used in California by at least 10% by 2020 relative to a 2010 baseline. The program is administered by the California Air Resources Board (CARB). The original regulation was adopted in April 2009. Various amendments have been made to the legislation including an amendment in February 2015 which slightly altered the trajectory of the target (Table 1.5).

Providers of transport fuels (obligated parties) must show that the mix of fuels they sell meet each year's LCFS intensity standards. They must report all fuels provided and track the fuel's carbon intensity through a system of "credits" and "deficits." Credits are generated when a fuel used has a lower carbon intensity than the standard, while deficits are created when a fuel has a higher carbon intensity. A regulated party meets its obligation by demonstrating that the credits earned offset their deficits. The standard is defined in terms of metric tons of GHG emissions. Credits may be banked and traded within the LCFS and credit prices are published on a regular basis.

All biofuels used for the LCFS must undergo a life cycle analysis to calculate their GHG emissions. By 2015, 233 fuel pathways with lower carbon intensities than their fossil counterpart had been certified. Almost 170 biofuel plants are registered under the LCFS as supplying low carbon fuels to California. The approach has helped to support innovation and development of cleaner fuels as the policy directly rewards biofuels for their GHG savings.

Table 1.5: LCFS compliance schedule for diesel fuels

Year	Average Carbon Intensity (Diesel) (g CO_2 e/MJ)	Carbon Intensity (CI) Comparator	CI reduction mandated under LCFS
2011	94.47	94.71	0.25%
2012	94.24	94.71	0.50%
2013	97.05	98.03	1%
2014	97.05	98.03	1%
2015	97.05	98.03	1%
2016	99.97	102.1	2.0%
2017	98.44	102.1	3.5%
2018	96.91	102.1	5.0%
2019	94.36	102.1	7.5%
2020 onwards	91.81	102.1	10.0%

In Europe, GHG reduction mandates may represent the future direction of EU/state policy. Germany has already adopted such a mandate while Sweden and the UK are considering its adoption. In Germany, the quota rises from 3.5% GHG savings in 2015 to 4.0% in 2017 and 6% in 2020. The penalty for non-compliance is a punitive €0.47/kg CO_2 equivalent. The program has supported the use of cleaner fuels in transport.

End-user incentives or penalties

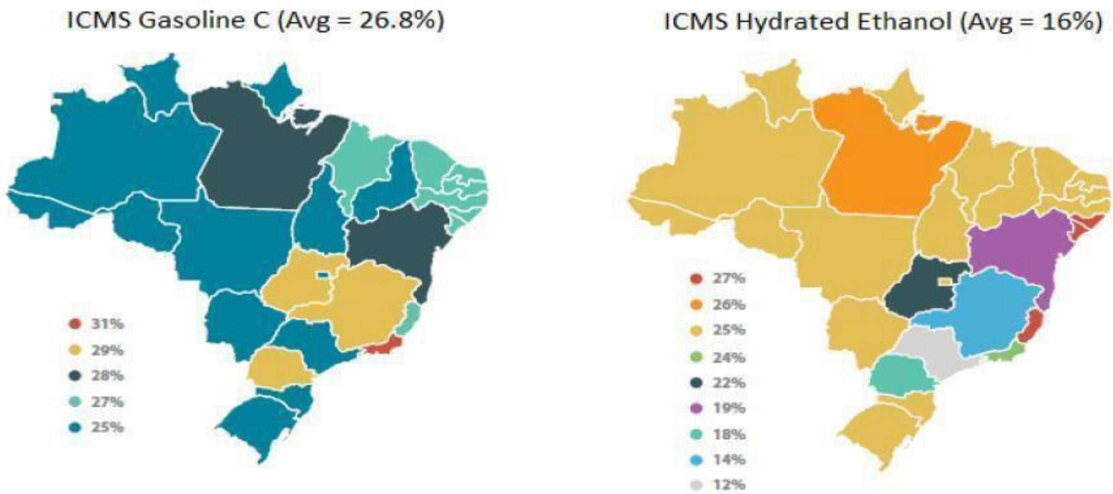
The enforcement of mandates is essential to a program's success and this can be achieved through the provision of either tax concessions or penalties. In the early stages of a fuel ethanol program, tax concessions are an effective way to promote demand but they come at the expense of government revenues.

In Brazil, tax concessions long have played, and continue to play an important role in stimulating demand for ethanol. Flex-fuel cars generally attract lower rates of sales tax than gasoline cars allowing them to be sold at a lower price to the consumer.

Preferential treatment is also given to ethanol at the pump, although the value of the incentive has varied over time and across states. Since May 2004, the Contribution for Intervention in Economic Domain (CIDE) tax on ethanol has been set at zero while gasoline has been taxed at R$0.18-0.28/liter. In June 2012 the CIDE on gasoline was also set to zero, removing ethanol's advantage. However, in February 2015 the government decided to raise taxes on gasoline and diesel to offset the government's public account deficit. The value of the combined CIDE/PIS/COFINS taxes on gasoline was raised by R$0.22/liter, reinstating the advantage to ethanol. The PIS/COFINS tax is for the Social Integration Program/Contribution for Financing Social Security.

In addition to federal incentives, there are also state incentives to use ethanol. The ICMS is a sales tax which varies from state to state and is usually set at a lower level on ethanol relative to gasoline. The ICMS charged on ethanol varies from 12% in Sao Paulo to 27% in Pará. The ICMS for gasoline varies from 25% in most states to 31% in Rio de Janeiro. Map 1.1 highlights the ICMS set by each Brazilian state for 2016, according to the Fuels Industry Syndicate (Sindicom).

Map 1.1: ICMS tax on gasoline C and hydrous ethanol

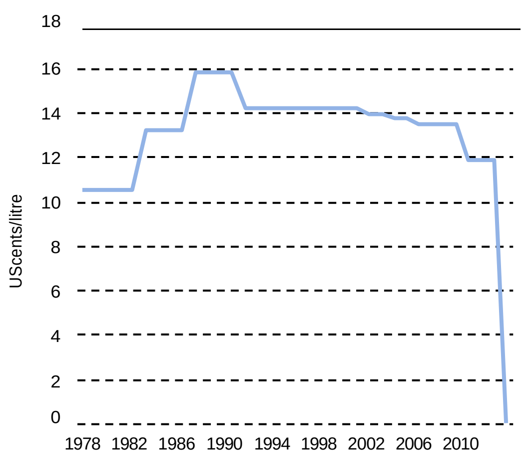


Source: SINDICOM.

The EU is another example of where tax concessions were used in the early days to promote demand. Often ethanol was granted a full tax exemption from mineral oil tax. These generous tax concessions were gradually replaced by penalties, as such subsidies ceased to be compliant with the EU's rules on state aid.

Blender tax credits are an effective way of supporting a fledgling ethanol industry. In the early days of the U.S. fuel ethanol program, a Volumetric Ethanol Excise Tax Credit (VEETC) was available to ethanol blenders.

Diagram 1.8: The U.S. Volumetric Ethanol Excise Tax Credit (VEETC)



As Diagram 1.8 reveals, the VEETC was progressively reduced from 16 cents/liter in the mid-1980s to 12 cents/liter as the market for ethanol developed. The credit was eventually abolished at the end of 2012. By this point, ethanol production costs had declined to the point where it was cheaper to produce than gasoline and refiners no longer needed the compensation of the tax credit. Moreover, a new system for compliance was established – Renewable Identification Numbers (RINs).
This system of traded certificates could also offer compensation to refiners if ethanol became more expensive than gasoline. This occurred in 2015 when crude oil prices fell to a low level.

Thailand currently has the most generous incentives available to promote consumption. These incentives entice the consumer to buy gasohol at the pump by pricing it at a lower level than gasoline. In June 2016, E-10 was priced at a $0.24/liter discount relative to gasoline, with even larger subsidies being applied to higher level blends (Table 1.6). This policy has been extremely effective at stimulating demand.

Table 1.6: Summary of end-user incentives available in the featured economies

Economy		Incentive/penalty
Canada		None but producer incentives available
Peru		None
Philippines		Ethanol exempt from mineral oil tax
Thailand		$/liter subsidy on gasohol:
	E10 95	*0.24*
	E10 91	*0.26*
	E20	*0.32*
	E85	*0.42*
U.S.		None, RINs ensure compliance

Note: RINs are Renewable Identification Numbers. 1 gallon of ethanol generates 1 RIN. RINs comprise a 22-digit serial number recording key details of the biofuel such as year of production, plant, batch and RFS category. Surplus RINs can be sold. At the end of the mandate year, refiners demonstrate compliance with the mandate by showing they have acquired the appropriate number and type of RINs.

Producer incentives

While the majority of subsidies have been targeted at stimulating demand for ethanol, there are a few examples of producer incentives. Such incentives are commonly used to support the development of a fuel ethanol industry and are usually reduced as the industry matures.

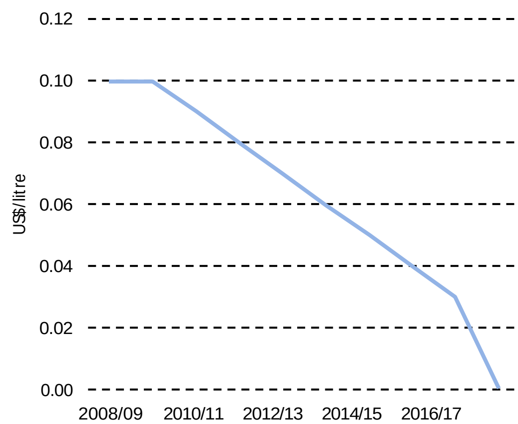
In the U.S., a small producers' tax credit of US$0.10/gallon (US$0.03/liter) was available between 2005 and the end of 2011. Qualifying plants had to have no more than 60 million gallons (227 million liters) of capacity and the credit was available only on the first 15 million gallons (57 million liters) of supply. The credit had to be offset against a company's income tax liability.

The U.S. still has a US$1/gallon (US$0.26/liter) producer credit on cellulosic ethanol as this industry is under development. For second generation biofuel plants starting operations between 2006 and 2013, the U.S. also had a depreciation tax allowance. The tax allowance was available only for the first year of the plant's operation and was equal to 50% of the adjusted basis of the property. Most states have general investment tax credits designed to support business. In the early days of the ethanol industry, many states (including South Dakota and Nebraska) had both investment and producer incentives that were specifically targeted at the ethanol industry.

Prior to 2007 Canada supported ethanol consumption through a reduction in mineral oil tax, the level of which depended on the state.

However, in the federal budget of April 2007 there was a marked shift in the approach to policy making. Specifically, the state-specific tax concessions were abolished in favor of a nation-wide producer tax credit, the evolution of which is shown in Diagram 1.9. From 2008/09 (Mar/Apr), the incentive was set at C$0.10/liter (US$0.11/liter), falling to C$0.03/liter (US$0.04/liter) in 2016/17. After this date the incentive will sunset. Qualifying facilities had to be constructed before March 2011 and had to meet a minimum supply volume. Plants also had to report on and meet minimum standards of environmental performance.

Diagram 1.9: The evolution of Canada's ethanol production incentive



Neither Thailand nor Peru have any production incentives available but in the Philippines, entities engaged in the Plantation of biofuel feedstocks are allowed to import farm machinery duty free and are exempt from VAT.

Low versus high level ethanol blends

The majority of ethanol mandates prescribe the use of ethanol in a relatively low percentage blend of ethanol in gasoline. This is because gasoline cars face technical limits regarding how much ethanol they can use. In the U.S., E-10 is the main blend sold in the market. Although the EPA has approved E-15 for use in vehicles manufactured after 2001, and new cars are warrantied for E-15, most cars on the road are still only warrantied for E-10. In addition, E-10 must continue to be sold alongside E-15 meaning that additional pumps must be installed in petrol stations. This has slowed the pace of E15 adoption. In Europe, cars are currently warrantied for just E-5. With car manufacturers often opposing higher blends of ethanol, this so-called "blend wall" has constrained growth in the fuel ethanol markets of the EU and U.S.

However, a way to circumvent the blend wall is to use flex-fuel vehicles. Flex-fuel vehicles can operate on any blend of gasoline and ethanol. Brazil is the best example of where flex-fuel vehicles (FFV's) have made a significant contribution to fuel ethanol demand.

Brazil was the first economy to embrace ethanol as a fuel. Following the oil crisis in 1973, the Brazilian government made blending ethanol with gasoline compulsory and promoted the expansion of cane-based ethanol production. Since then, Brazil has gone through three main phases, as illustrated in Diagram 1.8.

- ***Ethanol-only (E100) vehicle boom (late 70s - early 90s)***. This period saw the rapid increase in the number of E100 vehicles powered by hydrous ethanol. Such vehicles could only operate on hydrous ethanol. As a result, demand for hydrous rose rapidly, while anhydrous ethanol consumption (in gasoline) stagnated.

- ***Return to gasoline (early 90s - mid-2000s)***. Following hydrous ethanol supply problems, the early 1990s saw a return to gasoline-powered vehicles, increasing the demand for anhydrous at the expense of hydrous ethanol.

- ***FFV boom (mid-2000s - date)***. From the mid-2000s, however, the trend has moved in the opposite direction. The rapid adoption of flex-fuel vehicles (FFVs) has boosted sharply the demand for hydrous ethanol, taking demand to new highs.

It should be noted that in addition to hydrous ethanol consumed in flex fuel cars, Brazil also uses anhydrous ethanol blended in gasoline. The blending rate of ethanol in gasoline is currently set at its maximum of 27.5% but the government has the discretion to vary the blend between 18% and 27.5%. In contrast to hydrous ethanol, demand for anhydrous ethanol has been more stable (Diagram 1.10).

Diagram 1.10: Hydrous vs. anhydrous ethanol demand in Brazil over time

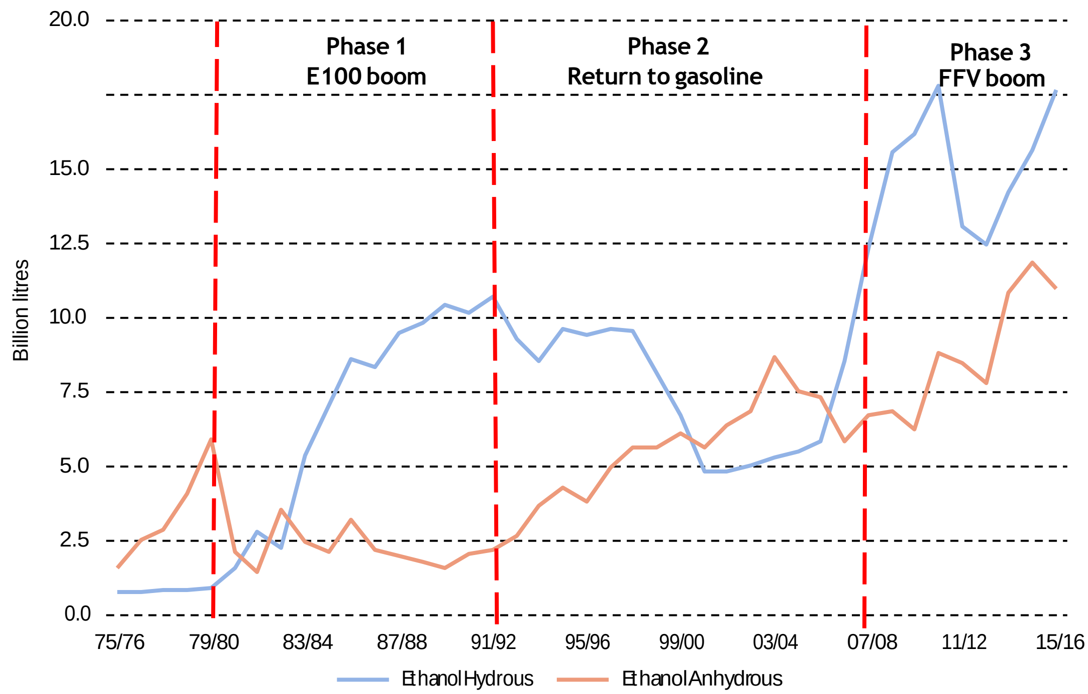


Diagram 1.11: The evolution of Brazil's car fleet

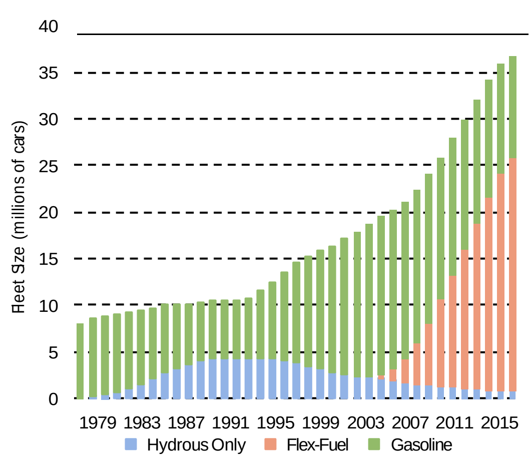


Diagram 1.11 highlights how the distribution of Brazil's car fleet has changed over time. The E100 car fleet peaked in the early nineties and then began a terminal decline as ethanol fell out of favor and gasoline cars became popular again. 2003 saw the introduction of FFV's. They proved to be extremely popular with the result that FFV's now account for 90% of all new car sales. Overall, FFV's comprise just over two thirds of Brazil's car fleet. This has created huge potential demand for hydrous ethanol if it is priced competitively with gasoline. In recent years, consumption has been running at less than half of its potential as supply has been constrained.

- Since 2011/12, it appears that the government's desire to control the gasoline price is pushing the industry into a new phase, where the majority of motorists (even those driving FFV's) use gasoline rather than ethanol. In 2015, only around 25-30% of flex-fuel car drivers used hydrous ethanol in their vehicles.

- In the last seven years, the government has made small changes that have helped ethanol and gasoline producers (given surging oil prices and costs), but have done little to change things at the consumer level, which is ultimately the price with which ethanol must compete. In November 2014, the government increased the gasoline price by 3%, while in February 2015, the CIDE/PIS COFINS tax on gasoline was reintroduced. Both these measures provided a small boost to ethanol prices.

- While lower world gasoline prices have certainly helped the government's cause, there is a need to improve Petrobras' financial position in order to support the investments that are required to develop the economy's off-shore oil fields. Moreover, there remains the issue of the infrastructure needed to import large quantities of gasoline. While further investment in gasoline refining capacity is expected prior to 2018, Brazil's oil refining business is likely to be focused on fuel oil and diesel. This is mainly due to the fact that most of Brazil's new oil reserves will produce 'sour' crude oil, which is more expensive to turn into gasoline because of its high sulfur content.

- It seems clear that Brazil will not invest significantly in new gasoline refining capacity. Given the current composition of the car fleet, this means that the government will either have to (a) invest in more capacity to import gasoline, or (b) raise gasoline prices to encourage the domestic cane industry to expand.

- Brazilian fuel ethanol demand had been stable for decades until around 2007, ranging between 10 billion liters and 13 billion liters from 1988-2006. Its growth since then is linked to the rise in sales of FFV's. FFV sales began to rise sharply in 2006. 847,000 such vehicles were sold in 2005, increasing to 1.4 million in 2006 and reaching 3.2 million units in 2013. The growth in sales of FFV's has increased the potential demand for ethanol significantly, since such vehicles can be fueled with hydrous ethanol (~96% ethanol), as well as anhydrous ethanol. Correspondingly, sales of hydrous ethanol have ramped up. Sales rose from 5.9 billion liters in 2006 to 12.3 billion liters in 2008. Sales have fluctuated since then as Diagram 1.8 reveals. In 2015, fuel ethanol consumption reached a record 26.8 billion liters. However, demand was boosted by the economic recession, which led consumers to purchase hydrous ethanol at the pump because it had a lower absolute price than gasoline.

Brazil has experience of both low and high level blends through its anhydrous (gasohol) and hydrous (flex fuel) ethanol markets. Demand for anhydrous ethanol is relatively stable year-on-year as it depends on gasoline sales which have a tendency to increase over time. By contrast, demand for hydrous ethanol is more volatile as it depends on the competitiveness of ethanol prices relative to gasoline. The experience of Brazil highlights that the initial first step for any government considering a fuel ethanol program should be to implement a low level blend in gasoline.

Administration of biofuel programs

Biofuel programs require administrative support and several government agencies are often involved in overseeing their implementation. Their administration involves:

- Creation of a government body to oversee compliance with mandates

- Organizations for the promotion of biofuels and administration of subsidies

- Research and development into new production technologies

- Auditing and certification systems for ensuring that biofuels meet sustainability criteria

- Financial reporting on tax revenues, subsidies and costs
- Creation of industry associations

In Canada, energy is legislated and overseen at both federal and state levels and thus ethanol is overseen by both national and state bodies. Environment Canada is the national body overseeing compliance with the Renewable Fuels Regulations.

In Peru, The Biofuels Market Promotion legislation establishes the technical committee responsible for determining blend rates and schedules, as well as recommends biofuel production and commercialization regulations. The committee is also responsible for enhancing public awareness of the benefits of biofuels. The Ministries of Energy and Mines, Economy and Finance, Agriculture, Peru's Investment Agency (PROINVERSION), Alternative Development Agency (DEVIDA), and the private sector comprise the technical committee.

The Philippine biofuel program is administered by the Department of Energy (DOE). The department works closely with the Sugar Regulatory Association (SRA). Similarly in Thailand, the Ministry of Energy is responsible for overseeing the implementation of the Alternative Energy Development Plan.

In the U.S., the key government bodies involved in biofuels are the EPA, EIA and the U.S. Department of Agriculture (USDA). The EPA oversees the implementation of the RFS and collects data on compliance. It also operates the RIN system, which allows biofuel certificates to be traded. The EIA collects data on transport fuel consumption and works closely with the EPA in converting the RFS mandate into blending obligations for refiners. Finally, the USDA overseas the production of corn and tracks how much corn is being used for ethanol production. The USDA also operates a number of programs into the research and development of new technologies in ethanol production.

Trade policies

Low tariffs and open markets are essential to ensuring consistent, steady supplies of fuel ethanol. With open markets, ethanol will eventually displace unsustainable crude oil. The ethanol import tariffs in most APEC economies are given in Table 1.7. Some APEC economies such as Australia; Indonesia; Mexico; Russia; and Viet Nam have high or restrictive tariffs. It is also worth noting that many net importers of crude oil have no import tariffs on petroleum products but have restrictive tariffs on ethanol. Ethanol will displace oil if it is allowed to compete on a level playing field.

In the early days of an ethanol industry's development, it may be beneficial to impose tariffs but as an industry matures, these tariffs are usually reduced and abolished. This trend has been seen in Brazil and the U.S. The U.S. abolished its ethanol import tariff of 54 c/gal (14.3 c/l) at the end of 2011. The tariff had originally been put in place to prevent importers from benefiting from VEETC, which had originally been set at the same level as the tariff. Prior to this, the Caribbean Basin Initiative (CBI) gave eligible economies a duty free quota equal to 7% of domestic consumption. As dehydration confers origin status, many CBI economies imported Brazilian ethanol for dehydration and re-export to the U.S. The abolition of the import tariff has removed the incentive for this trade.

Table 1.7: Ethanol import tariffs (MFN) in APEC economies

	Undenatured 220710	Denatured 220720
Australia	5% of FOB value + 81.21 AUD/ liter of pure alcohol	5% of FOB value + 0.396 AUD/ l
Canada	6.5% + 4.92 c/liter	0% + 4.92 c/liter
Chile	6%	6%
China	40%	5%
Indonesia	30%	30%
Japan	10% if for ETBE, otherwise 0%	27.2% (...2010) or 38.1 JPY/lt (...2020)
Korea	30%	8.0%
Malaysia	60.0 MYR/ liter of pure alcohol	1.0 MYR/ liter
Mexico	10% + 0.36 USD/ liter	10% + 0.36 USD/ liter
New Zealand	51.795 NZD/ liter of pure alcohol	0.0%
Peru	6%	6%
Philippines	10%	10%
Russia	100%, but not less than 2.0 EUR/ l	100%, but not less than 2.0 EUR/ l
Singapore	0%	0%
Thailand	80 Baht/liter	2.50 Baht/liter
US	2.50%	1.90%
Viet Nam	40%	20%

MFN = Most Favored Nation. MFN tariffs are granted to members of the WTO.

The U.S. currently allows for the import of Brazilian ethanol to meet its advanced undifferentiated mandate under the renewable fuels standard. Fuel ethanol imports from Brazil qualifying for the RFS peaked at 2.1 billion liters in 2012 but have subsequently declined reaching just 337 million liters in 2015. The reason for the decline is that the undifferentiated mandate has been scaled back in recent years to allow for a greater contribution of biodiesel. In addition, there has been a rise in the volume of domestic biofuels that qualify for the undifferentiated mandate.

Low tariffs on ethanol mean that mandates can still be met in times of domestic supply problems. Allowing ethanol from overseas allows for greater diversification of supply, greater market competition and potentially lower prices for end

Summary of the benefits of ethanol and policy recommendations

Ethanol has demonstrable benefits in terms of:

- Mitigating climate change
- Improving air quality
- Offering a renewable alternative to fossil fuels

Moreover, the **environmental benefits are increasing over time** as plants become more efficient at reducing their fossil energy inputs.

The development of **cellulosic ethanol** offers the prospect of ethanol with an extremely low or even negative carbon footprint. The use of ethanol has made significant improvements to air quality in the U.S. and its replacement of MTBE as an oxygenate has prevented further contamination of ground water. Ethanol is a better quality fuel than gasoline with a higher octane rating, allowing blenders to blend lower quality gasoline and still meet fuel specifications.

Ethanol is beneficial for economic development. Research from Brazil, the EU and the U.S. demonstrates that three quarters of the economic benefit from ethanol is on agriculture, with industry and research & development also receiving a boost. The forward and backward economic linkages with ethanol ensure that the beneficial effects ripple out across the economy. Ethanol boosts household incomes, which in turn, is also beneficial.

Ethanol improves energy security and generates foreign exchange savings for those economies who are net importers of crude oil. While the last two years have seen crude oil prices at relatively low levels, it should be remembered that crude is a finite resource and that at some point, crude oil prices will recover.

Key ethanol policy measures include:

- Mandated low level ethanol blends
- Mandated higher level ethanol blends
- Financial supports for ethanol producers and end users

With regards to ethanol policy, there is virtue in simplicity. Mandated low level blends that are legally enforced are usually the most effective at stimulating demand. Blends of at least 10% can be used without modification of existing vehicles and no changes are needed in the retail sector if gasohol replaces gasoline. Ethanol requires additional tank storage at the refinery as well as modifications to the gasoline blend stocks so governments need to be willing to help refiners make the necessary changes. Low level blends allow ethanol to be priced at parity with gasoline, thus capturing more value. They also offer a stable and predictable level of demand. To ensure that mandates are met it is advisable to stipulate that every drop of gasoline contains a fixed proportion of ethanol. It may be that mandates have to be rolled out gradually across cities or states to accommodate any limitations in supply infrastructure. Consultation with car manufacturers is very important as consumers need reassurance that their engine warranties are valid for gasohol.

Once a successful low level blending program has been established, it may be worthwhile explore the potential for higher level blends such as E-85 or E100 (as in Brazil). Unlike low level blends which can use the existing car fleet, higher blends require the establishment of a flex-fuel car fleet. The experience of Brazil demonstrates that it takes several years for flex-fuel cars to penetrate the car fleet. In addition, ethanol must be priced competitively relative to gasoline to generate demand. In this circumstance it becomes even more important to ensure that there is an uninterrupted supply of ethanol. Having an open market policy and allowing imports can help in this regard.

Most governments with ethanol programs have provided fiscal support in the form of producer credits or tax concessions for end users. Producer credits are usually provided in the early days of a program, to encourage investment and allow new plants to be constructed. Once the industry is up and running, these incentives are usually scaled back and withdrawn. Similarly with end-user tax credits, these are often initially used to stimulate demand, in conjunction with mandates. However, once a supply infrastructure and market are established, these too are usually progressively reduced. Governments also need to be willing to support long-term research and development into ethanol, so that an industry can continue to exploit new low carbon raw materials and reduce their costs of production.