Special Report

A Report from the Advanced Motor Fuels Technology Collaboration Programme

Air Quality Implications of Transport Biofuel Consumption

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The text of this AMF Special Report was prepared jointly by AMF experts and IEA experts as a subsection on air pollutant emissions from biofuels and fossil fuels of the IEA's renewable energy market report 'Renewables 2018.' The text is based on knowledge gained through AMF work and on information displayed in the Fuel Info section of the AMF website.

AMF Fuel Info: *http://iea-amf.org/content/fuel_information/fuel_info_home*
IEA Renewables 2018: *https://www.iea.org/renewables2018/*

Air Quality Implications of Transport Biofuel Consumption

Many countries have initiated policy support for biofuel consumption to reduce transport sector CO_2 emissions. However, transportation is also a key contributor to urban air pollution, which is a pressing issue in many large cities. How biofuels compare with fossil fuels in terms of air pollutant emissions that negatively affect human health is therefore a key consideration in their use.

To understand the impact of biofuels on air pollutant emissions from road vehicles, there are two determining factors to consider: first, the combination of the vehicle's engine and exhaust aftertreatment technology;[1] and second, the characteristics of the biofuel compared with the fossil fuel being replaced. Taken together, these two components provide an indication of the performance of biofuels relative to fossil fuels in terms of air pollutant emissions and impact on human health.

Air pollutant emissions from road transport and their impact on human health

Road vehicle exhaust emissions contain an array of pollutants that negatively impact human health. Many of these can be grouped under the following categories:

- Nitrogen oxide compounds (NO_x): Within this category, nitrogen dioxide (NO_2) is generally the most damaging to health, as it irritates the respiratory tract and after long-term exposure can lead to reduced lung function, chronic cardiovascular diseases and lung cancer.

- Volatile organic compounds (VOCs): This category comprises volatile hydrocarbons and carbonyl compounds. VOCs such as 1,3-butadiene, benzene and formaldehyde are classified as carcinogenic, while acetaldehyde is classified as potentially carcinogenic. VOCs may also irritate the skin, eyes and respiratory tract, and induce cellular inflammation.

[1] Also referred to as emissions control technology.

- Particulate matter (PM): This grouping includes ultrafine particles, black carbon and associated compounds, e.g. polyaromatic hydrocarbons (PAHs). Health effects of PM relate to particle size and composition. Diesel PM is classified as carcinogenic to humans. PM has also been linked with heart, pulmonary and Alzheimer's disease.

Other transport-related air pollutants that can also damage human health include carbon monoxide (CO) and products formed from chemical reactions involving the emissions listed above.

Influence of engine type and aftertreatment technology on air pollutant emissions

With sophisticated engines and aftertreatment technology, the effect of a fuel's chemical and physical characteristics on tailpipe emissions is greatly reduced. For vehicles that comply with the latest emissions standards,[2] most tailpipe air pollutant emissions reach very low levels regardless of the fuel used. For older vehicles, however, fuel type can significantly influence air pollutant emissions. Therefore, fuel selection is particularly relevant in many emerging economies and developing countries with large urban agglomerations and older vehicle fleets.

Vehicle engine type also determines the exhaust aftertreatment technology that can be used. Spark-ignition engines can use gasoline, ethanol or, with small modifications, methane (e.g. natural gas or biomethane), and air pollutant emissions from spark-ignition engines can be reduced to very low levels through a three-way catalyst (TWC). In contrast, diesel engines require a more complex and expensive system that includes a particulate filter and a selective catalytic reduction catalyst to control emissions. In addition, maintaining the high exhaust temperatures needed for proper catalyst operation is more challenging for diesel than spark-ignition engines.

[2] Examples include Euro 6 in Europe and US Tier 3. Sophisticated engines discharge less than 5% the air pollutant emissions of less sophisticated or uncontrolled engines.

How does biofuel consumption alter air pollutant emissions compared with fossil fuels?

The air pollutant emissions impacts of ethanol and biomethane as substitutes for gasoline, and of FAME biodiesel and HVO as diesel substitutes, are outlined below:

- **Ethanol** generally results in lower air pollutant emissions when blended with gasoline, with the level of emissions falling as the share of ethanol rises. This improvement is especially notable for PM, wherein lower emissions from high-ethanol blends are achieved with direct-injection spark-ignition engines. Ethanol also reduces tailpipe CO emissions; however, cold starting is more challenging with E85 than with gasoline, potentially raising VOC emissions, and higher ethanol blends can increase acetaldehyde emissions compared with gasoline.

- **Biomethane** delivers low CO, PM and VOC emissions when used in a spark-ignition gas engine. NO_x emissions vary significantly depending on engine and exhaust aftertreatment technology; they are low for engines with a properly functioning TWC and higher for less sophisticated lean-burn gas engines, for which there is some evidence of elevated formaldehyde emissions.

- **FAME biodiesel** used at high blend levels decreases CO, VOC and PM emissions, potentially up to 50% in less sophisticated engines. However, at high blends FAME increases NO_x emissions compared with fossil diesel as a result of higher oxygen content and subsequently higher combustion temperatures.

- **HVO** has high ignition quality and the paraffinic nature of the fuel improves combustion and thus reduces CO, hydrocarbon and PM emissions compared with regular diesel. Unlike FAME biodiesel, HVO also has potential to reduce NO_x emissions up to 10%. Of all fuels suitable for use in diesel vehicles, HVO delivers the lowest exhaust mutagenicity.

Net effect of biofuel consumption on air pollutant emissions

The IEA’s ‘Advanced Motor Fuels’ technology collaboration programme (TCP) compared the emissions of various fuels by category of air pollutant. For cars with less sophisticated engines, air pollutant emissions are higher from diesel engines than from spark-ignition (gasoline) engines (Table 1). With cars that meet the equivalent of a Euro 3 emissions standard, e.g. manufactured around the year 2000 in Europe, biomethane has the most potential to deliver low air pollutant emissions.[3]

E85 blends can deliver lower PM emissions than fossil gasoline in older cars, but the reduction is relatively minor. For more widely consumed low-ethanol blends, e.g. E10, the effects on air pollutant emissions are less pronounced than for higher blends, although in older engines without catalysts, E10 can reduce CO and VOC emissions to a small extent. In catalyst-equipped cars the impact of ethanol blending on emissions is minor.

Table 1 Air pollutant emissions by fuel from modern and older cars

	Modern cars			Older cars		
Fuel	NO_x	PM	VOCs	NO_x	PM	VOCs
Gasoline	Green	Yellow	Yellow	Green	Green	Orange
Ethanol (E85)	Green	Green	Yellow	Green	Green	Orange
Biomethane	Green	Green	Green	Green	Green	Yellow
Diesel	Orange	Green	Green	Red	Red	Orange
FAME Biodiesel	Orange	Green	Green	Red	Orange	Yellow
HVO	Orange	Green	Green	Orange	Orange	Yellow

Emissions from lowest to highest (left to right): [Green] [Yellow] [Orange] [Red]

Notes: Older = Euro 3 or equivalent (e.g. model year 2000 in Europe); modern = vehicles that meet Euro 6 emissions standards or equivalent. Assessing the relative performance of biofuels compared with fossil fuels in terms of air pollutant emissions, and therefore health impact, is complex. Consequently, ranking different fuels according to health impact can be subject to debate because biofuels can decrease some air pollutant emissions compared with fossil fuels while increasing others. Consideration must also be given to the fossil fuel substituted, how the biofuel is consumed, e.g. blended (at a low or high share) or unblended, and the level of sophistication of the vehicle's engine and aftertreatment technology. In addition, the relative health risks of different air pollutants must also be taken into account. PM categorisation for modern cars is made on the basis that direct injection gasoline engines have higher PM emissions than particulate filter-equipped diesel cars.

In modern cars, biomethane again delivers the lowest emissions, while ethanol in high blends can reduce PM emissions compared with gasoline for cars with direct injection engines. For older diesel engine cars, FAME biodiesel and HVO generally improve air quality compared with fossil

[3] Gasoline vehicles can be converted to use natural gas/biomethane. However, qualified retrofitting companies and robust testing are required to verify performance.

diesel. FAME biodiesel results in higher NO_x emissions than HVO, however. In modern diesel cars, fuel type has a minimal effect on air pollutant emissions.

For heavy-duty vehicles, diesel engines are currently standard. Old heavy-duty engines exhibit pronounced differences in air pollutant emissions depending on the fuel (Table 2). Conversely, new heavy-duty vehicles meet the highest emissions standards and have low air pollutant emissions regardless of the fuel used. FAME and HVO can reduce air pollutants from older engines (e.g. Euro 3 standard or equivalent), while biomethane vehicles perform best in terms of reduced air pollutant emissions compared with fossil diesel.

Table 2 Air pollutant emissions by fuel from modern and older heavy-duty vehicles

	Modern heavy-duty			Older heavy-duty		
Fuel	NO_x	PM	VOCs	NO_x	PM	VOCs
Diesel	Yellow	Green	Green	Red	Red	Orange
FAME Biodiesel	Yellow	Green	Green	Red	Orange	Yellow
HVO	Yellow	Green	Green	Orange	Orange	Yellow
Biomethane	Yellow	Green	Green	Yellow	Green	Yellow

Emissions from lowest to highest (left to right): Green, Yellow, Orange, Red

Note: Please see note below Table 1.

Given the composition of vehicle fleets over the Renewables 2018 forecast period and beyond, the ability of biofuels to reduce air pollutant as well as CO_2 emissions could drive policy support for their use. This is especially the case in countries with pressing air quality concerns due to older vehicle fleets (or lax emissions standards for new vehicles) and large urban agglomerations.

Generally, low-income and lower-middle-income countries tend to have a higher vehicle scrappage age than higher-income countries. In addition, in many countries and regions (e.g. Africa, Eastern Europe and Mexico) imports of older used vehicles that perform poorly in terms of air pollutant emissions than modern equivalents are also prevalent.

Air quality benefits from biofuel use may be particularly attainable in countries such as India, Indonesia and Thailand, which have a higher average age for vehicle scrappage and domestic biofuel consumption policies (Table 3). Since the relative improvement in air pollutant emissions is greater for diesel than for gasoline vehicles, a further consideration in terms of emissions reductions is the predominant fuel type used by the passenger vehicle fleet. For instance, less than 15% of Argentina's car fleet is diesel-fuelled (Vassallo, 2018), but diesel power trains command a higher market share in India; for heavy-duty vehicles, diesel is used almost exclusively worldwide. Furthermore, gasoline and diesel fuel specifications (e.g. regarding permissible sulphur content) also influence air pollutant emissions in vehicles built to less stringent emissions standards.

Table 3 Estimated average scrappage age of passenger and heavy-duty vehicles (years)

	Passenger cars	Heavy-duty vehicles
European Union	10 - 15	10 - 15
United States	16 - 20	10 - 15
Argentina	10 - 15	16 - 20
Brazil	16 - 20	16 - 20
Mexico	>25	21 - 25
India	21 - 25	21 - 25
Indonesia	21 - 25	21 - 25
Thailand	16 - 20	10 - 15

Note: Estimates based on 2015 market data.

Source: IEA (2018a), Modelling of the Transport Sector in the Mobility Model (MoMo), July 2018 version.

Regulations regarding permissible levels of air pollutant emissions for new vehicles and robustness of emissions testing practices, e.g. real-world testing conditions, are also valid factors in determining whether biofuels could offer benefits in terms of lowering air pollutant emissions.

Table 4 Euro emissions standards for NO_x and mass of particles (g/km) for passenger cars

	Gasoline		Diesel	
	NO_X	Mass of particles	NO_X	Mass of particles
Euro 1	0.97[1]	-	0.97[1]	-
Euro 2	0.50[1]	-	0.90[1]	-
Euro 3	0.15	-	0.50	-
Euro 4	0.08	-	0.25	-
Euro 5	0.06	0.0045[2]	0.18	0.0045
Euro 6	0.06	0.0045[2]	0.08	0.0045

Notes: 1 = expressed as HC + NOx; 2 = applicable to direct injection gasoline engines only. Euro 6 introduced limits for ultra-fine particles for direct injection gasoline engines that were not in place for Euro 5.

Source: ACEA (2018b), "Euro standards", www.acea.be/industry-topics/tag/category/euro-standards.

In the European Union, Euro 6 standards became mandatory for new registrations as of September 2015, but new vehicles are not produced to such stringent standards globally. Argentina instituted a Euro 5 emissions standard-equivalent for both light- and heavy-duty vehicles in 2016, while in 2017 India required Euro 4-equivalent standards nationwide.[4] Indonesia plans to upgrade from far less stringent Euro 2-equivalent standards for new gasoline vehicles in 2018, but for diesel vehicles it will take until 2021. Biofuels could therefore continue to play a role in reducing air pollutant emissions in these and other countries with less robust emissions standards for years to come.

For modern vehicles that comply with the latest emissions standards,[5] the difference in air pollutant emissions between biofuels and fossil fuels is minimal. Therefore, in the long term the transition to sophisticated internal combustion engine vehicles and to battery electric light-duty passenger vehicles that do not emit tailpipe air pollutants weakens the case for biofuels as a means to improve air quality. However, their potential to reduce CO_2 emissions means sustainable biofuels will still be useful in the long-term decarbonisation of the transport sector, especially for long-distance heavy-duty trucking, aviation and marine transport.

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[4] India's standards are termed 'Bharat Stages'; stage 4 norms were introduced in selected cities in 2010.

[5] For example, Euro 6 with compliance demonstrated by testing under real-world driving conditions, as is now required in Europe.

References

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