UNIT 8 ETHANOL PRODUCTION

Structure

8.0 Objectives

8.1 Introduction

8.2 Biofuels

8.3 Status of Biofuels

8.4 Advantages and Disadvantages of Biofuels

8.5 Ethanol

- 8.5.1 Production of Ethanol
- 8.5.2 Properties of Ethanol
- 8.5.3 Utilization of Ethanol

8.6 Let Us Sum Up

8.7 Key Words

8.8 Suggested Further Reading/References

8.9 Answers to Check Your Progress

8.0 OBJECTIVES

After studying this Unit, you should be able to:

- explain the concept, sources and importance of biofuels in the current energy scenario;
- figure out the advantages and challenges associated with biofuels;
- discuss about various resources and technologies for biofuels production;
- explain the various production methods of ethanol; and
- describe the properties of biofuels and learn about the application and utilization aspects of various biofuels.

8.1 INTRODUCTION

Utilization of fuels to fulfil energy needs is an important activity in our day-to-day life. Energy is required by entities including industries, transportation, construction and domestic needs. Fossil-based fuels, including coal, petroleum and natural gas, are a source of various other fuels such as gasoline, diesel, kerosene, compressed natural gas, etc. However, fossil fuels are for a limited period of time. It is projected that after 2042, coal will be the only fuel remaining on earth; oil and gas will have finizhed by that time. Therefore, alternative fuels need to be searched to fulfil our energy demands. In addition to this, there is a growing concern for the environment. The carbon dioxide level in 2021 reached up to 414.72 ppm, which is a serious concern. High levels of carbon dioxide not only increaze global earth temperature but also the acidity level of oceans. Alternative fuels, which could replace conventional fuels and, at the same time, are safe for the environment, are important for human survival on the earth.

In this Unit, we will discuss about biofuels, specifically ethanol. Apart from their environmental and energy advantages, biofuels present vast business opportunities across production, processing, logistics and technology innovation. The growing demand for ethanol, bio-diesel and biogas has encouraged investment in bio-refineries, waste-to-energy plants and rural-based enterprises. Sectors like automotive, aviation and agriculture are increazingly integrating biofuels to achieve sustainability targets. Startups and agribusiness ventures are also exploring second-generation biofuels derived from crop residues and municipal waste, which offer both environmental and economic gains. Thus, biofuels not only represent a pathway to a cleaner future but also a vibrant business ecosystem fostering innovation, employment and rural empowerment.

8.2 BIOFUELS

The fuels that are derived from biomass are known as biofuels. In today's era of rising energy demands and environmental concerns, biofuels have emerged as a sustainable and strategic alternative to fossil fuels. They play a crucial role in reducing greenhouse gas emissions, enhancing energy security, and promoting rural and agricultural development. According to the International Energy Agency (IEA), biofuels accounted for nearly 4.5% of global transport energy demand in 2023, and this share is expected to rise significantly by 2030, driven by policies promoting carbon neutrality and renewable energy use. India, being the world's third-largest energy consumer, has set an ambitious target of 20% ethanol blending in petrol by 2025, which could potentially save around USD 4 billion annually in oil imports while reducing carbon dioxide emissions by nearly 7-8 million tonnes per year.

They can serve as options to secure energy demand as well as be safe for the environment. Ethanol, methanol and butanol are prime examples of biofuels that are suitable for their application in spark ignition (SI) engines. The biomass for producing biofuels is agricultural waste, sugarcane, wheat crops, forest waste, algae, etc. Since biofuels are produced from biomass, they fix carbon dioxide. When they are used as fuel, they releaze carbon dioxide. In this way, they behave as carbon-neutral fuels. Biofuels are classified into four generations.

First-generation biofuels are produced from food crops such as sugarcane, wheat and corn. Second-generation biofuels are produced from non-food biomass such as wheat straw and rice husk. Biofuels produced from algae and cyanobacteria are classified as third-generation biofuels. Fourth-generation biofuels are generated from genetically modified microorganisms using thermochemical processing of carbon dioxide.

Table 8.1: Types of Biofuels Based on the Source

Type of Biofuel	Source / Production Process	Energy / Efficiency	Environmental Benefits	Applications / Uses
Bioethanol	Derived from corn and sugarcane using a fermentation process.	One litre of ethanol provides approximately two-thirds of the energy of petrol.	Improves combustion performance and lowers emissions of carbon monoxide and Sulphur oxides.	Used as a blend with petrol to enhance fuel efficiency and reduce emissions.
Bio-diesel	Produced from vegetable oils (soybean, palm), vegetable waste oils, and animal fats through Transesterification.	Comparable efficiency to diesel fuel.	Emits very low or negligible harmful gases compared to diesel.	Serves as an alternative to conventional diesel in vehicles and machinery.
Biogas	Produced by anaerobic decomposition of organic matter such as animal and human sewage.	Methane-rich gas provides high calorific value.	Utilises waste efficiently and reduces greenhouse gas emissions.	Commonly used for cooking, heating, electricity generation, and as vehicle fuel.
Biobutanol	Produced through the fermentation of starch, similar to bioethanol.	Has the highest energy content among gasoline alternatives.	Reduces emissions when blended with diesel.	Used as a fuel additive, a solvent in the textile industry, and a base for perfumes.
Biohydrogen	Produced through processes such as pyrolysis, gasification, or biological fermentation.	High energy density and efficiency.	Clean fuel as water, is the only byproduct after combustion.	Potential alternative to fossil fuels for power generation and transport.

Source: *Dristi IAS*

8.3 STATUS OF BIOFUELS

According to the United States Environmental Protection Agency (EPA), global demand for biofuels is expected to increase by 32 per cent between 2023 and 2028. One-fifth of this demand growth can be attributed to the return to pre-COVID-19 demand levels. The main driving force for the biofuels increased demand includes the government policies, Feldemad in transportation, type of transportation being adopted, costs and specific policy design influence where growth occurs and which fuels grow the fastest. Depending upon the policies adopted in Europe and the United States, the demand for renewable bio-diesel has increazed by three times. The combined demand for bio-diesel, renewable diesel and biojetfuels in 2021 was 15% higher than in 2019. Biojet fuel is a biofuel for powering aircraft. The growth in demand for biofuels is mainly driven by renewable diesel demand in the United States and Asian bio-diesel demand. Due to strong domestic policies, rising liquid fuel demand, and export-driven production, Asia is expected to surpass total European biofuel production in the future. India is encouraging the use of ethanol blends. A 20% blending ratio is being targeted throughout the country. In addition to this, Indonesia and Malaysia are also bringing bio-diesel blend targets. North American biofuel demand is expected to grow the most by 2026, but 40 per cent of this growth is due to demand recovery following Covid-19 declines. The United States and Brazil continue to be the largest centres of biofuel demand. They are the chief leaders in biofuels production in the world.

In the Indian Context

India started the first ethanol blending pilot programme in 2001. The target was to blend 5% ethanol into the gasoline. In 2011-12, the National Mission on Bio-diesel was laid down. It aimed to achieve 20% bio-diesel in diesel. It established the biofuel mission in the country. It was followed by the National Biofuel Policy (NBP) in 2009, and the revised NBP was launched in 2018.

By 2017, the NPB 2009 envisaged an optional blending target of 20% for both ethanol and bio-diesel. The goal of NPB 2009 was to make it easier to develop domestic biomass feedstock for biofuel production. The NPB 2009 established the vision, goals and strategy for biofuel development, as well as a framework of financial, institutional, and technological interventions.

The revized biofuels policy, NPB 2018, went into effect on May 16, 2018, and proposed an indicative blending target of 20% ethanol in gasoline and 5% bio-diesel in diesel by 2030. The goal of NPB 2018 is to reduce crude oil imports, increaze farmer income, create jobs, optimise dryland use, and contribute to sustainability. As of the ongoing Ethanol Supply Year (ESY) 2024-25 (Nov 2024-Oct 2025), India is making strong progress in ethanol blending: for instance, blending reached around 17.98 % by February 2025 (and about 19% in some reports) of petrol. Beyond ethanol, new targets and frameworks: For example, the Compressed Biogas (CBG) Programme blending requirement is expected to become mandatory from FY 2025-26 onwards, initially at ~2.5 % and reaching 5 % by FY 2028-29. The policy aims to provide financial and fiscal incentives based on the type of biofuel, which is classified as first-generation, second-generation, third and fourth-generation. It aims to facilitate the biofuels production under the Make in India program by manufacturing units located in special economic zones.

8.4 ADVANTAGES AND DISADVANTAGES OF BIOFUELS

Understanding both the advantages and disadvantages of biofuels is essential for developing balanced policies and sustainable energy strategies.

Advantages

1. **Suitability for Internal Combustion Engines**

   Various properties, such as high octane number and the presence of oxygen in biofuels, have tremendous benefits when they are used in engines. The engines provide high thermal efficiency compared to conventional gasoline fuel.

2. **Energy Security**

   Utilization of biofuels reduces the dependency on fossil fuels, thus enhancing the energy security of a country. It is important to note that biofuel production and consumption will not directly reduce GHG or conventional pollutant emissions; however, they reduce petroleum imports or relieve pressure on finite resources in and of themselves. For these benefits to be realised, biofuel production and use must coincide with reductions in the production and use of fossil fuels.

3. Positive Effects on the Economy

Production of biofuels increases the economic activities in the country. It generates employment in allied industries, thus empowering the economy of the country.

4. Reduction in Greenhouse Gases

Burning of fossil fuels generates high carbon dioxide levels in the atmosphere. Biofuels generally have less carbon-to-hydrogen ratio. It results in a lowering of carbon dioxide emissions. Methanol and ethanol are commonly used biofuels in SI engines, and they contain oxygen. Molecular oxygen helps in combustion and oxidises carbon monoxide and unburnt hydrocarbon emissions.

Disadvantages

1. Since biofuels production depends on biomass. Biomass could be edible crops, forests and the waste generated in agricultural activities. Production of biofuels would put pressure on land, water and other resources, such as food prices. Many crops used as biofuel feedstocks would otherwise be used for human consumption directly or indirectly as animal feed. Cellulosic feedstocks can also compete for resources (land, water, fertilizer, and so on) that could otherwise be used to produce food. Therefore, biofuel production and consumption might bring certain undesirable results.
2. Overuse of land for biofuels could lead to the emission of GHG due to the releaze of carbon into the atmosphere. Too much production of cellulosic feedstocks could put extra pressure on agricultural practices. The price of edible crops might rise, and the ecology might get disturbed, resulting in biodiversity losses. Too much use of chemicals for farming might lead to land pollution. Biofuel feedstocks grown on deforested tropical forest land, such as soybeans in the Amazon and oil palm in Southeast Asia, emit a disproportionate amount of greenhouse gases.
3. For the production and processing of biofuels, the biorefineries use fossil fuels as their energy source. It might lead to emissions such as hydrocarbons and oxides of nitrogen.
4. The research indicates that the production of biofuel feedstocks from food crops, including corn and soya, may increase water pollution from nutrients, pesticides, and sediment. Increased irrigation and ethanol production might lead to the destruction of water resources. Air quality may also be affected due to biofuels-based tailpipe emissions and additional emissions from biorefineries.
5. Several studies found a 20 to 40% increaze in corn prices from biofuels from 2007 to 2009 in the National Research Council's (2011) report. Although the range of estimates in the literature is wide, economic models show that biofuel use can result in higher crop prices. Higher crop prices could result in higher food prices and, in general, affect the economic activities.

Check Your Progress 8.1

Note: a) Write your answers in the space given below.

b) Answers are given at the end of the unit.

1) What are the different types of biofuels based on the source?

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2) Mention the benefits of biofuels.

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8.5 ETHANOL

Ethanol, also known as ethyl alcohol (C_2H_5OH), is a renewable biofuel produced primarily through the fermentation of biomass such as sugarcane, corn, maize or other starchy crops. It is a clear, colourless liquid with high octane value and is widely used as an alternative or blending fuel with petrol to reduce dependency on fossil fuels. In India, ethanol has gained remarkable importance under the Ethanol Blended Petrol (EBP) Programme, launched to mix ethanol with petrol and thereby reduce carbon emissions and crude oil imports.

Ethanol production primarily comes from molasses, a by-product of the sugar industry. To meet the growing blending demand, the government has diversified feedstock sources to include damaged food grains, surplus rice, maize, and agricultural residues, encouraging the development of second-generation (2G) bioethanol plants. According to the Ministry of Petroleum and Natural Gas, India achieved an average 15% ethanol blending with petrol in 2024, with the goal of reaching 20% (E20) blending by 2025, five years ahead of the original 2030 target.

The adoption of ethanol blending offers multiple benefits. It strengthens energy security, reduces the import bill (saving nearly ₹41,500 crore in 2023-24), provides additional income avenues for farmers, and supports sustainable rural development. However, challenges remain, such as the high water requirement of sugarcane-based ethanol, infrastructure constraints and limited availability of advanced bioethanol technologies. Despite these challenges, ethanol represents a key pillar of India's renewable energy transition, aligning with the nation's broader goals of achieving net-zero emissions by 2070 and promoting Atmanirbhar Bharat (self-reliant India) in energy production.

8.5.1 Production of Ethanol

Starch-Based Ethanol Production

Starch is a widely used ethanol feedstock. Long chains of glucose molecules make up the molecules that make up starch. Thus, after dissolving starch molecules into straightforward glucose molecules, starchy materials can also be fermented. Cereal grains, potatoes, sweet potatoes, and cassava are a few examples of the starchy materials frequently employed worldwide to produce ethanol. To convert starch into fermentable sugars from starchy sources, starch must react with water in a process known as hydrolysis (saccharification).

Usually, to achieve hydrolysis, starch and water are combined to create a slurry, which is then agitated and heated to burst the cell walls. At certain points during the heating cycle, particular enzymes are added to dissolve the chemical bonds. Different pathways of ethanol production are given in Fig. 8.1.

Dry Mill and Wet Mill Processes

Either a dry-mill or wet-mill technology is used to create ethanol from feedstocks that are based on starch and sugar. Through a process called dry-milling, corn is ground into flour and fermented into ethanol along with by products like distillers' grains and carbon dioxide. Dry milling involves first turning the entire grain kernel into "meal," which is then slurried with water to create a "mash." In order to turn starch into sugar, enzymes are introduced to the mash. After being cooked, the mash is cooled down and put into fermenters. Once the yeast is added, sugar starts to turn into alcohol.

Microorganisms that are involved in fermentation use fermentable sugars as food, and as a result, ethanol and other byproducts are produced. The 6-carbon sugars, including glucose, which is one of the most popular, may normally be used by these microbes. As a result, biomass materials that contain a lot of glucose or glucose precursors are the simplest to turn into ethanol. The ethanol is then distilled and dehydrated after fermentation.

Starch, protein, and fibre in corn are separated using wet mills before being converted into ethanol. The grain is initially broken down into its constituent parts through soaking before wet milling. The slurry is put through grinders to separate the corn germ after steeping. Further distinctions are made between the remaining fibre, gluten, and starch components. To create animal feed, the protein component of gluten is filtered and dried. The residual starch can then undergo a process similar to the dry mill process to ferment into ethanol.

Cellulose-Based Ethanol Production

Producing cellulosic ethanol is more complex than producing ethanol from starch-based crops because it uses non-food biomass such as grass, wood, paper, crop residues, and other fibrous plant materials. These lignocellulosic materials are composed of cellulose, hemicellulose, and lignin, where lignin provides structural strength and makes cellulose and hemicellulose difficult to access for conversion.

Cellulosic ethanol can be produced through bio-chemical or thermo-chemical processes. In the bio-chemical method, biomass undergoes pretreatment to release hemicellulose sugars and hydrolysis to break cellulose into fermentable sugars. The remaining lignin is recovered and used to generate energy for the fermentation process, which converts sugars into ethanol. In the thermo-chemical route, biomass is heated and chemically treated to produce syngas (a mix of carbon monoxide and hydrogen), which is then converted into ethanol and other co-products using catalysts.

Among the production techniques, acid hydrolysis, enzymatic hydrolysis, and thermo-chemical conversion, acid hydrolysis is the most common, typically using sulfuric acid due to its low cost. While cellulosic ethanol offers environmental benefits and uses renewable waste materials, its production remains more energy-intensive and technically challenging compared to starch-based ethanol.

Acid Hydrolysis

Acid processes are classified into two types: dilute acid and concentrated acid, each with its own set of modifications. Dilute acid operations are carried out at high temperatures and pressures, with reaction durations in seconds or minutes, allowing for continuous processing.

Enzymatic Hydrolysis

Enzymatic hydrolysis is another fundamental mechanism of hydrolysis. Enzymes are naturally occurring plant proteins that catalyse chemical processes. However, for enzymes to function, they must have access to the molecules to be hydrolysed. To expose the cellulose and hemicellulose molecules, some form of pretreatment method is required to break the crystalline structure of the lignocellulose and remove the lignin. Physical or chemical pretreatment procedures may be applied depending on the biomass type. High temperature and pressure, milling, radiation, or freezing are all physical procedures that demand a lot of energy. A solvent is used in the chemical technique to break apart and dissolve the crystalline structure.

Thermo-chemical Processes

There are currently two ethanol production technologies that use thermo-chemical reactions in their processes. The first system is a mix of thermo-chemical and biological processes. The synthesis gas (a mixture of hydrogen and carbon oxides) is bubbled through specially engineered fermenters after the biomass materials have been thermo-chemically gasified. Under certain process conditions, a microbe is capable of converting the synthesis gas introduced into the fermenters to cause fermentation to ethanol. Microorganisms are not used in the second thermo-chemical ethanol production method. In this process, biomass materials are first thermo-chemically gasified, and the synthesis gas is then fed through a reactor containing catalysts, converting the gas to ethanol.

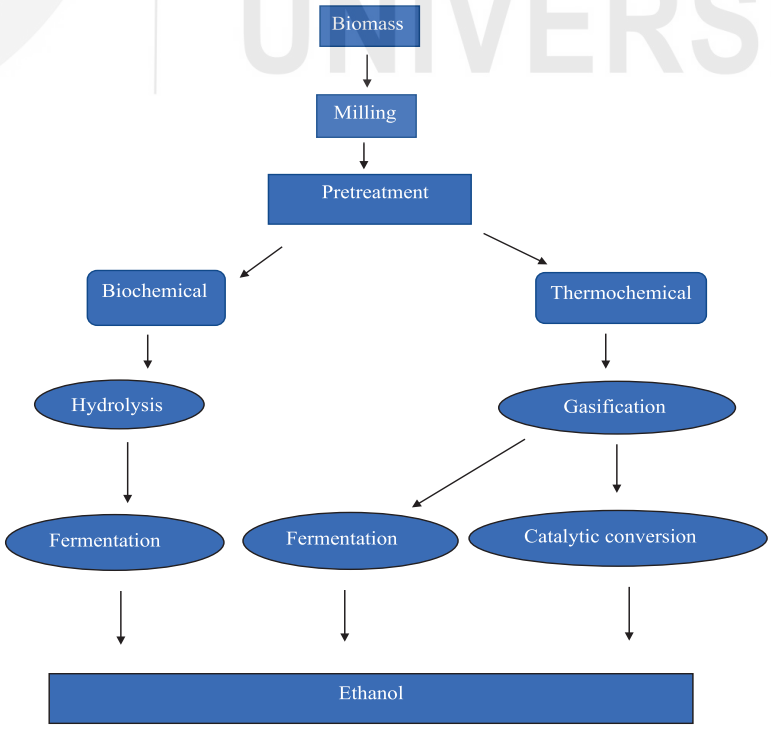

Fig. 8.1: Pathways of Ethanol Production

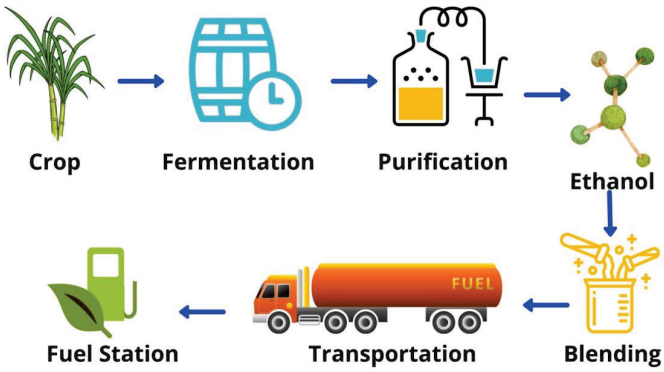

Fig. 8.2: End-to-End Ethanol Production

Source: *Dristi IAS*

8.5.2 Properties of Ethanol

Ethanol contains two carbon atoms with oxygen (34% by mass). The octane number of ethanol is greater than 100, which ensures knock-free operation at high compression ratios in a spark ignition engine. The calorific value is one-third of gasoline, and the flame speed is higher, which is beneficial for complete combustion. High flame speed enables to achievement of constant volume combustion. High latent heat of vaporisation helps increase the volumetric efficiency of the engine due to the enhanced cooling effect. Ethanol can be used as a blend with gasoline and in pure form. Being a liquid, it is easy to store like gasoline. The physico-chemical properties of ethanol are given in Table 8.2.

Table 8.2 : Properties of Ethanol

Properties	Ethanol
Composition	C_2H_5OH
Carbon (% mass)	52.14
Hydrogen (%mass)	13.13
Oxygen (% mass)	34.7
Density STP, kg/m^3	790
Dynamic viscosity (20^{0}C, mPa)	1.2
RON Research octane number (min.)	109
Boiling point (^{0}C)	79
Latent heat of vaporisation (kJ/kg)	838
Low calorific value (MJ/kg)	26.95
Flame speed (cm/s)	39
Stoichiometric air/fuel ratio	9

8.5.3 Utilization of Ethanol

Ethanol is a suitable fuel for SI engines due to its properties, including high autoignition temperature, high octane number, high flame speed, etc. The presence of molecular oxygen in ethanol is responsible for better combustion inside the cylinder. The calorific value is about 27 MJ/kg, which is lower than gasoline and higher than methanol. It can be stored easily like gasoline.

Alcohols, fuels, especially methanol and ethanol, pose material compatibility issues. Methanol, being more aggressive, reacts and damages various materials used in an IC engine. Ethanol can be used in pure form as well as can be blended with gasoline. For utilization in pure form, the operating parameters of the engine need to be optimized for methanol and ethanol fuels.

Government Initiatives for Ethanol Blending:

- PM-JI-VAN Yojana– Supports second-generation ethanol production from agricultural waste.
- National Bio-Energy Programme– Promotes ethanol and other biofuels for sustainable energy.
- Interest Subvention Scheme – Provides financial support for setting up ethanol plants.
- GST Reduction– Ethanol for EBP programme taxed at 5% (reduced from 18%) to encourage adoption.

Check Your Progress 8.2

Note: a) Write your answers in the space given below.

b) Answers are given at the end of the unit.

1) Ethanol can be used in ..... .

(a) SI engine (b) CI engine

(c) Both the SI and CI engines (d) None of the above

2) Which of the following is the easiest to break down for ethanol production?..... .

(a) A C6 sugar feedstock (b) Cellulose

(c) Lignin (d) Hemicellulose

3) Ethanol can be used in SI engine at high compression ratio since it has ..... .

(a) High flame speed (b) High octane number

(c) Low carbon content (d) All of the above

4) What is ethanol, and why is it considered a renewable biofuel?

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5) What are the major benefits of ethanol blending in India?

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6) What are some government initiatives supporting ethanol production in India?

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8.6 LET US SUM UP

The importance of biofuels for internal combustion engines has increazed in the recent past due to energy security concerns. Every country wants to become energy sufficient and self-reliant. The fossil fuels are limited and will diminish in a short period of time. Therefore, researchers worldwide are finding solutions to combat energy as well as environmental concerns. In this Unit, you have learnt about various biofuels, their production methods and their utilization aspects. The benefits of using methanol, ethanol, butanol and biogas as fuels were discussed. These are typical biofuels that are suitable for a spark ignition engine. Some key properties, such as octane number and calorific value, affect the engine performance. In addition to this, some aspects related to material compatibility were also added to give holistic aspects of the fuels. Utilization of biofuels could be fruitful as they are eco-friendly and carbon-neutral. Their utilization should be encouraged to achieve a sustainable future.

8.7 KEY WORDS

Carbon Dioxide (CO_2) : A greenhouse gas emitted during fuel combustion contributes to global warming.

Carbon Monoxide (CO) : A toxic gas formed from the incomplete combustion of fuel; harmful to human health.

Compression Ignition (CI) : An engine type where fuel is ignited by the high temperature and pressure of compressed air; used in diesel engines.

Hydrocarbon (HC) : Compounds of hydrogen and carbon found in fuels; unburned HCs contribute to air pollution.

Internal Combustion (IC) : A process where fuel combustion occurs inside the engine cylinder to produce power for motion.

Methyl Tert-Butyl Ether (MTBE) : An oxygenate additive used to improve petrol combustion and reduce emissions.

Motor Octane Number (MON) : Measures fuel performance under more severe engine conditions than RON.

National Policy on Biofuels (NPB) : India's policy framework promotes production, blending, and use of biofuels to enhance energy security and reduce emissions.

Oxides of Nitrogen (NOx) : Pollutant gases formed at high combustion temperatures cause smog and acid rain.

Reid Vapour Pressure (RVP) : A measure of a fuel's volatility; it affects fuel evaporation and engine performance.

Research Octane Number (RON) : Indicates a fuel's ability to resist knocking under mild driving conditions.

Spark Ignition (SI) : A type of engine in which the air–fuel mixture is ignited by a spark plug; commonly used in petrol engines.

Tert-Butyl Alcohol (TBA) : A chemical compound used as a fuel additive and intermediate in biofuel production.

8.8 SUGGESTED FURTHER READING/ REFERENCES

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8.9 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 8.1

1) Bioethanol, Bio-diesel, Biogas, Biobutanol, and Biohydrogen.

2) The important benefits are: Suitability for internal combustion engines, energy security, positive effects on the economy, and reduction in greenhouse gases.

Check Your Progress 8.2

1) c

2) a

3) b

4) Ethanol, also known as ethyl alcohol (C_2H_5OH), is a renewable biofuel produced primarily through the fermentation of biomass such as sugarcane, corn, maize, or other starchy crops. It is considered renewable because it is derived from plant-based materials that can be regrown, unlike fossil fuels, which are finite.

5) Ethanol blending reduces dependency on imported crude oil, lowers carbon emissions, provides income to farmers, promotes rural development, and contributes to India's goal of achieving net-zero emissions by 2070. In 2023-24, ethanol blending saved India nearly ₹41,500 crore in oil imports.

6) The major Government initiatives are:

   - **PM-JI-VAN Yojana:** Supports second-generation ethanol production from agricultural waste.
   - **National Bio-Energy Programme:** Promotes ethanol and other biofuels for sustainable energy.
   - **Interest Subvention Scheme:** Provides financial assistance for setting up ethanol plants.
   - **GST Reduction:** Reduced tax on ethanol for EBP from 18% to 5% to promote blending.