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Emissions and Alternative Fuels

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Monday

10.30 am

Universiti Teknologi Malaysia,
Johor Bahru, Johor

Biography

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Professional Recognition	Members in the Institute of Engineers Malaysia [IEM - 2023] Professional Technologist (Aerospace and Aviation technology) (P. Tech) [MBOT – 2022] Professional Engineer (Mechanical) (PE) [BEM– 2023]
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Website and Social Links	UTM Scholar https://utmscholar.utm.my/Scholar/ScholarInfoDetails/vynD Google Scholar https://scholar.google.com/citations?user=A2yRIbQAAAAJ&hl=en LinkedIn https://www.linkedin.com/in/ir-ts-dr-norazila-othman-357399158/

Outline

1. Overview of Emissions and Alternative Fuels
2. Principle of Conversion to Alternative Fuel
3. Feedstock and Alternative fuel Conversion
4. Example 1: Biodiesel
5. Example 2 and 3: Gasification & Pyrolysis
6. Conclusion

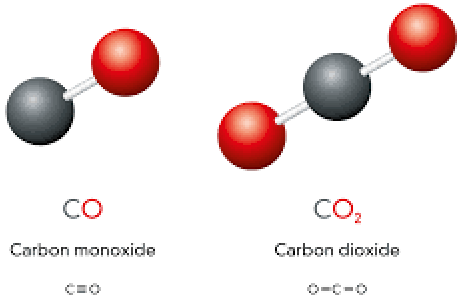
Overview of Emissions and Alternative Fuel

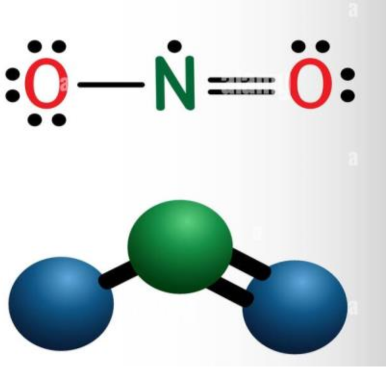
What are emissions?

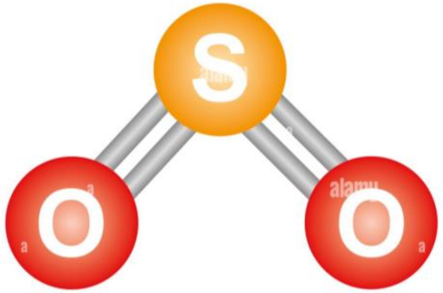
Emissions are the term used to describe the gases and particles which are put into the air or emitted by various sources.

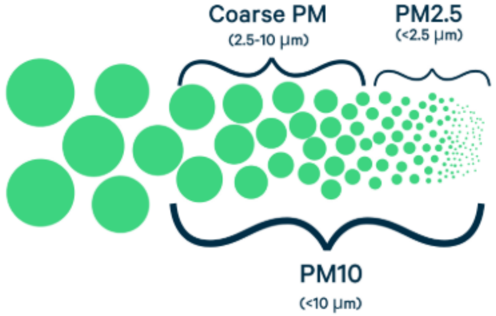
Types of emissions

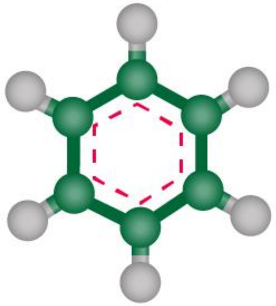
1. Oxides of carbon
2. Oxides of nitrogen
3. Oxides of sulfur
4. Hydrocarbons
5. Particulates

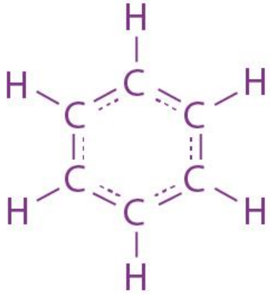




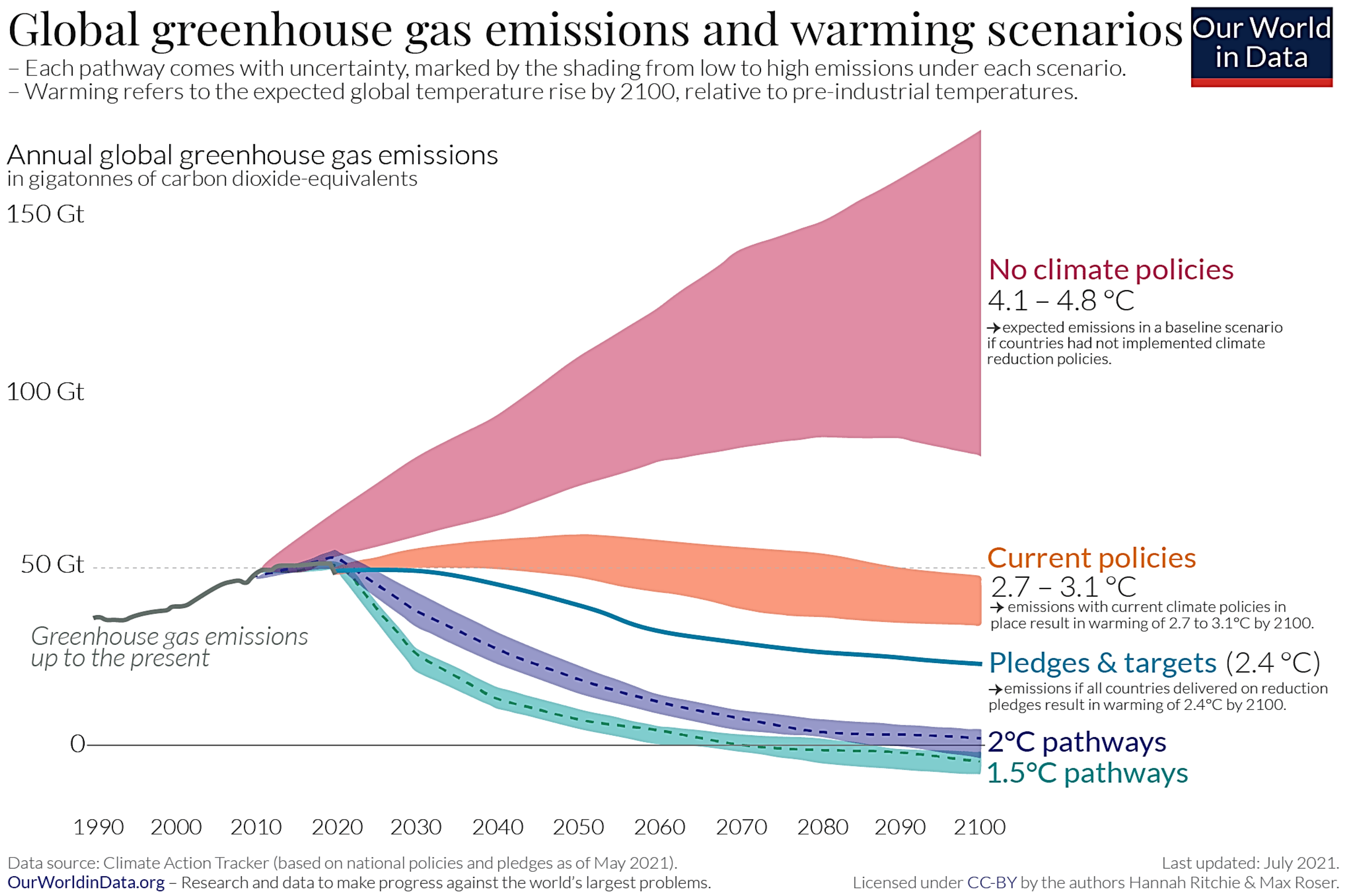






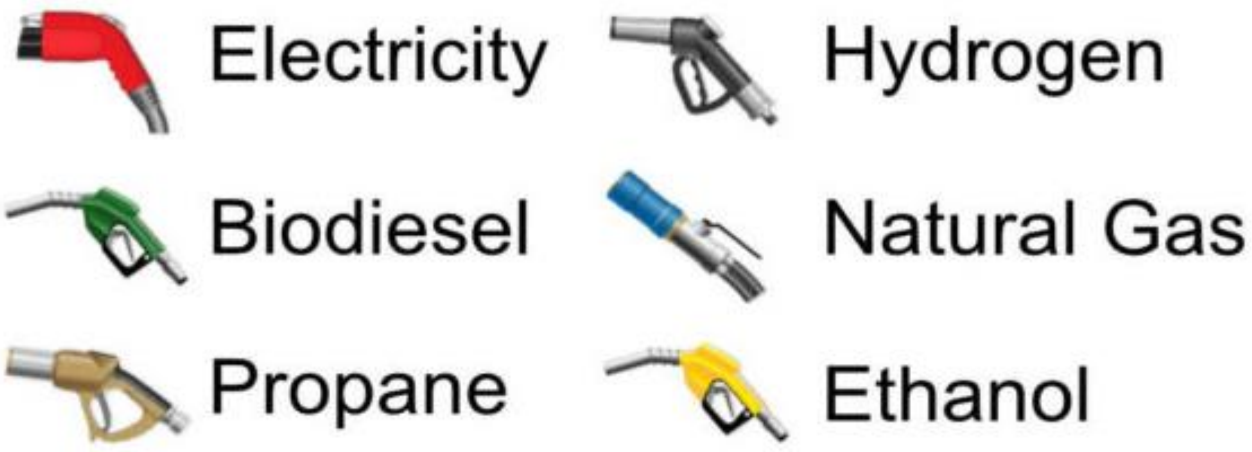


The Emission of Greenhouse Gases from Fossil Fuels



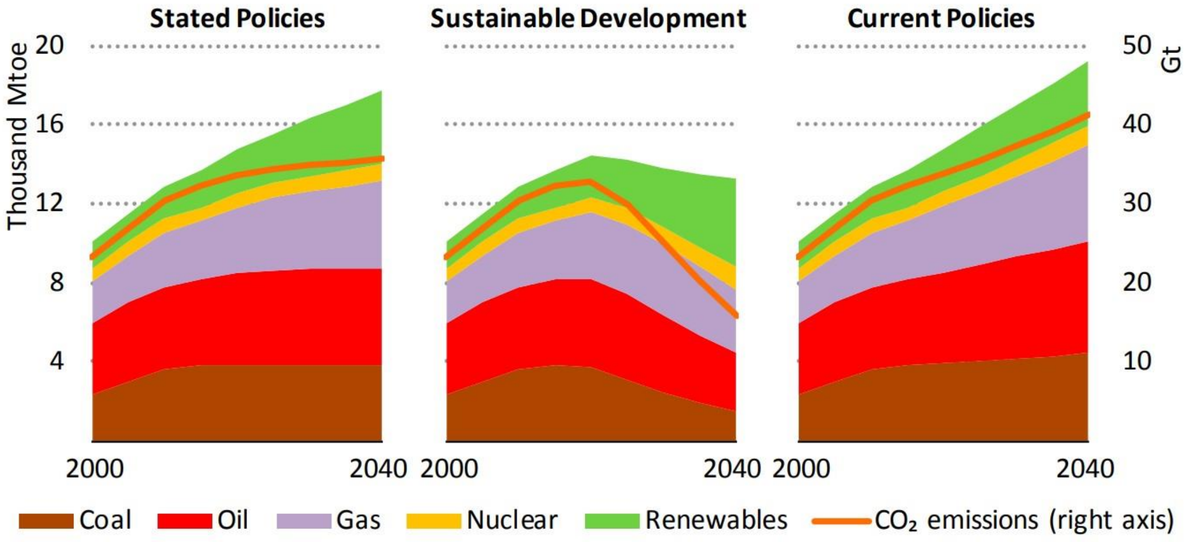
What are Alternative fuels?

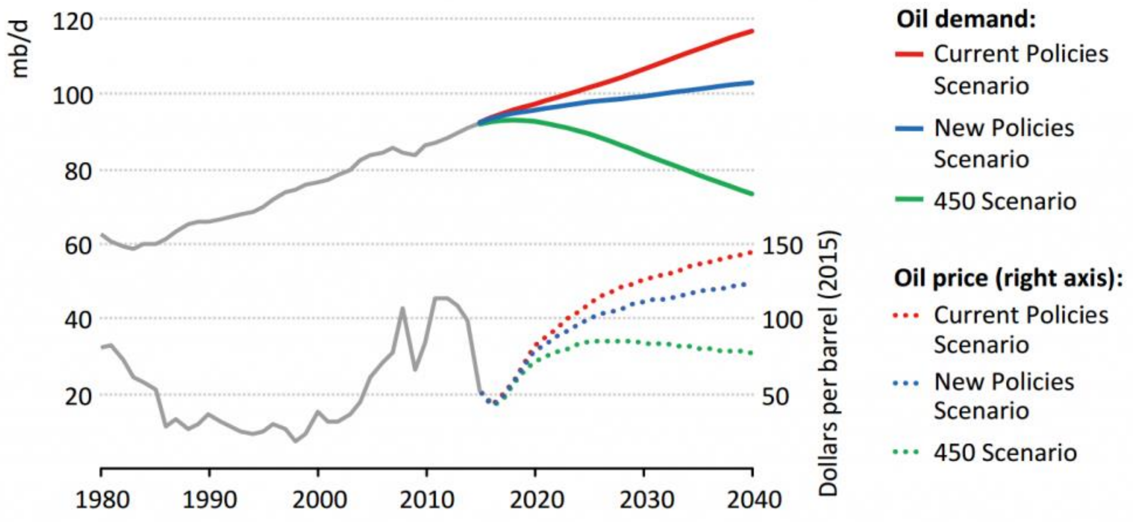
Alternative fuels are energy sources used to power vehicles and other machinery, offering a substitute for traditional fossil fuels like gasoline and diesel.



https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_january_2025.pdf

The Projection of Energy Demand & Oil Prices





- ❑ According to the United States Energy Information Administration, the graphical forecast on the world energy demand by fuel to 2040 estimated the trend of coal, oil, gas, nuclear and renewables based on the current, stated and sustainable development policies.

- ❑ The current policies (standard practice) projected that energy demand from fuel will grows as much as 50% while the stated policies (conservative energy plan) grows only a quarter in 2040.

- ❑ The grow of energy demand from both policies still contribute to the increase of CO_2 emission (orange line) as well as the continual increase on the fuel prices per barrel, which makes fuel still demanding and more expensive in the future.

Ethanol

Biodiesel

Fuel Ethanol Manufacturing Market (DDG & Corn Oil)

All corn and sugar cane based fuel ethanol plants that also include the production of by-products distillers dried grains and solubles (DDG) a high protein feed additivie plus corn oil used as feedstock for biodiesel production.

Biodiesel & Renewable Diesel

Biodiesel, Renewable Diesel and Sustainable Aviation Fuel (SAF) production from vegetable oils, used cooking oil, animal fats and even biomass. By-products of production also include the refining of glycerin.

Biorefineries (G2 & G3 Production)

Biorefineries that produce ethanol and renewable transportation fuel from second and third generation feedstocks meaning production from non-food feedstocks. G2 feedstocks include corn stover and bagesse material, wood chips and wood waste, cow manure, energy grassess, and tobacco. G3 feedstocks include algae, algae oil and seaweed.

Gasification (SynGas Production)

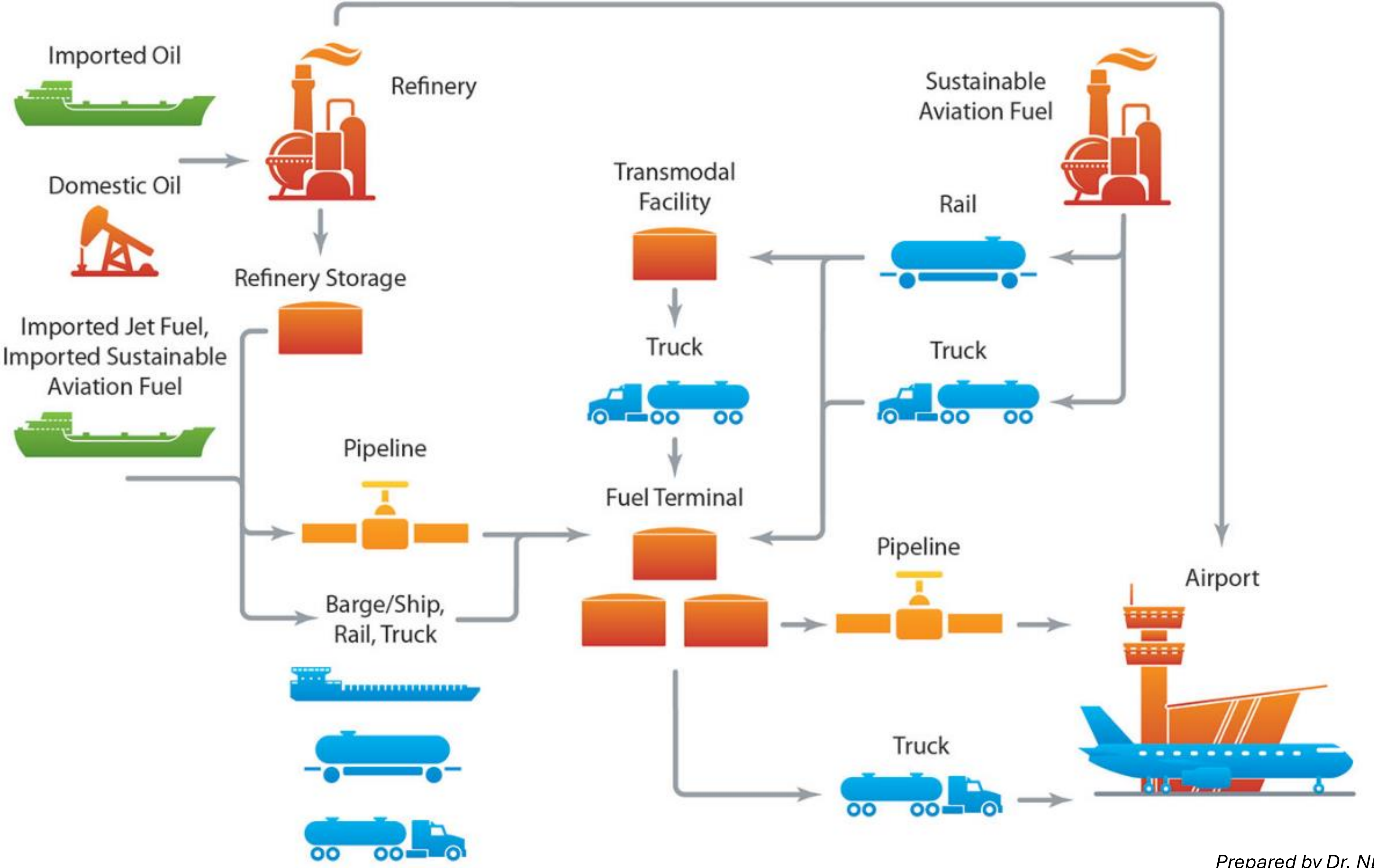
Facilities that gasify and liquify coal into syngas that is thermos-chemically transformed to produce diesel, gasoline, syngas and other fuels using Fischer-Tropsch and other technologies. Syngas can used as an alternative gas instead of burning fossil fuels.

Fuel Pellet Production

Facilities that manufacture fuel pellets from wood, grasses, and other biomass fired power generation, boilers and home heating.

Biogas / RNG / SNG

A group of gasses primarily used as a substitute for traditional natural gas and often referred to as Biogas, Renewable Natural Gas (RNG), Synthetic Natural Gas (SNG) or Clean Natural Gas (CNG). These gasses are produced using organic matter such as agricultural wastes, livestock manure, municipal waste, plant material, green waste or food waste as the primary feedstock.



https://afdc.energy.gov/fuels/sustainable-aviation-fuel

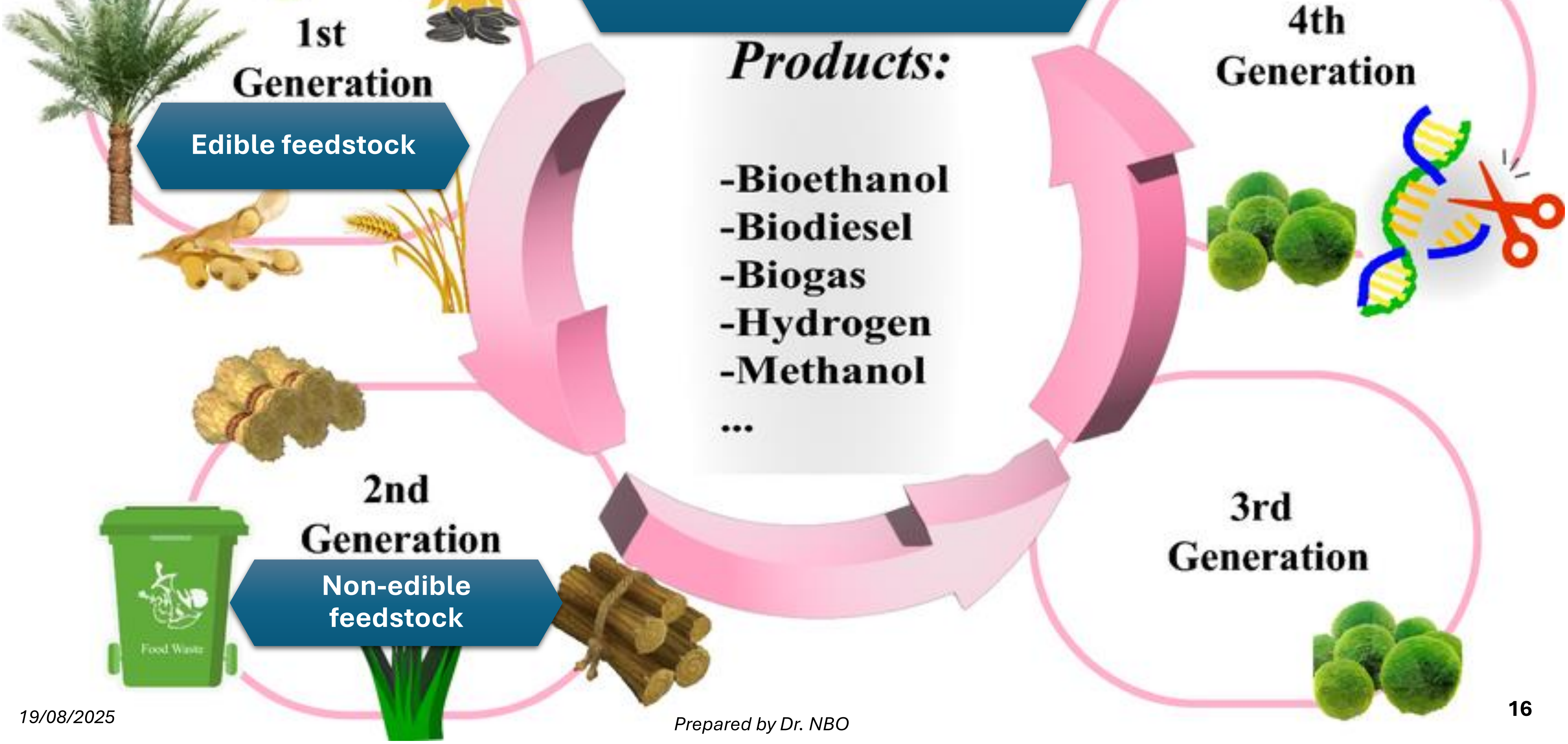
Principle of Conversion to Alternative Fuel

Principle

1. Feedstock Availability
2. Thermochemical Conversion
3. Well-to-Tank Analysis
4. Drop-in Fuels
5. Biochemical Conversion

Feedstock and Alternative Fuel Conversion

Feedstock


1st
Generation
Edible feedstock
Products:
-Bioethanol
-Biodiesel
-Biogas
-Hydrogen
-Methanol
...
4th
Generation
2nd
Generation
Non-edible feedstock
Food Waste
3rd
Generation

Biodiesel Edible and Non-edible Feedstock

Edible Biodiesel Feedstock

- Oil containing essential fatty acids from plants or animals fat used in preparation of food, flavourings and animal feed production.
- Usually being chosen as feedstock for biodiesel production due to its better yield and quality.
- High price for massive biodiesel production, which is economically unfeasible for commercial usage as compared to CDF.
- High demand in food industries to prepare food products for human and animals consumption, may cause significant food crisis if being used for massive biodiesel production.

Non-edible Biodiesel Feedstock

- Oil from non-consumable plants and waste cooking oil that do not compete with food or feed production.
- Biodiesel has many environmental benefits in biodiesel production and promote a balanced food versus fuel competition.
- Biodiesel production is much cheaper than edible feedstock, can be commercialise as alternative fuel for CDF.
- Most non-edible feedstocks contain high free fatty acids, which may require more processing for biodiesel fuel production than edible feedstocks.

Conversion

1.Pyrolysis

2.Gasification

3. Carbon Dioxide conversion

4. Biorefining

5. Liquefaction

Considerations

1. Environment Impact

SDG 7

7 AFFORDABLE AND CLEAN ENERGY

SDG 3

3 GOOD HEALTH AND WELL-BEING

2. Energy Efficiency

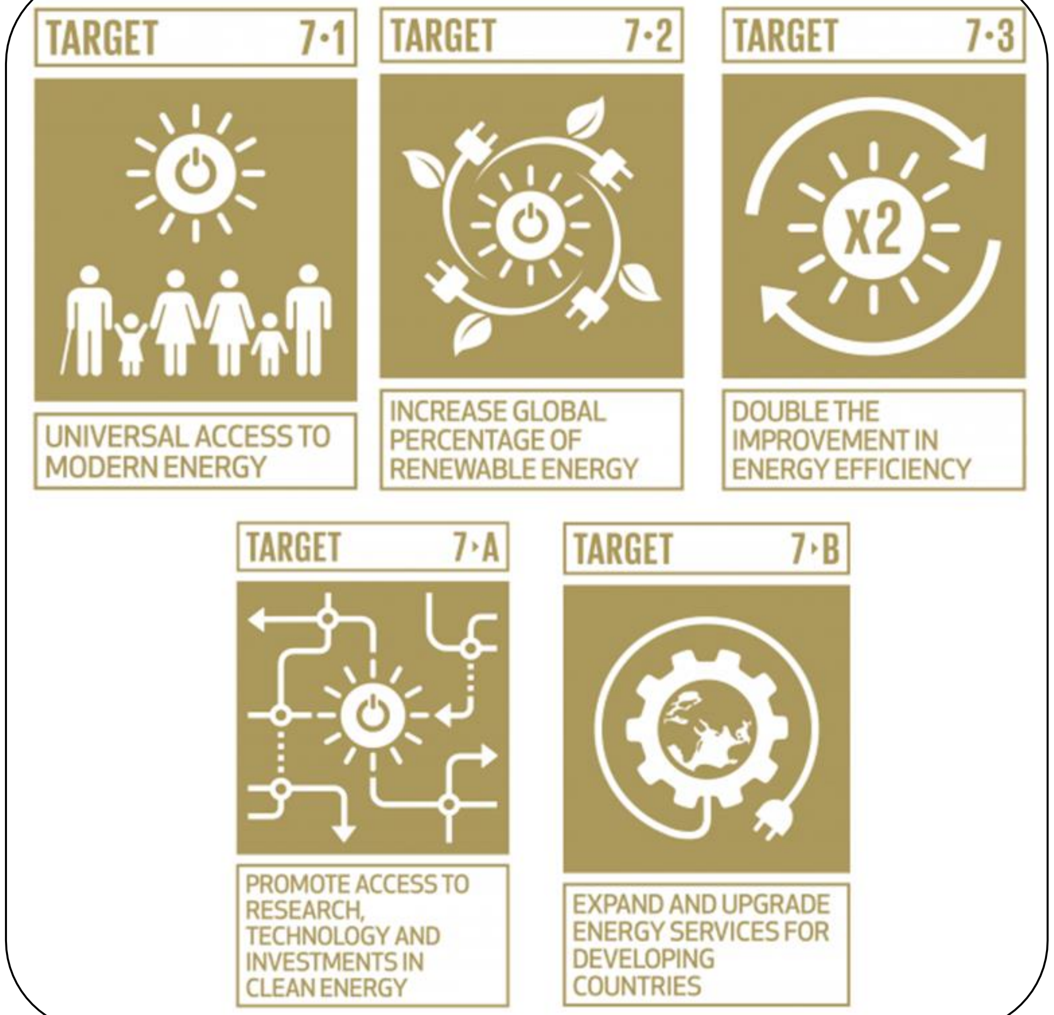
3. Economic Viability

SDG 13

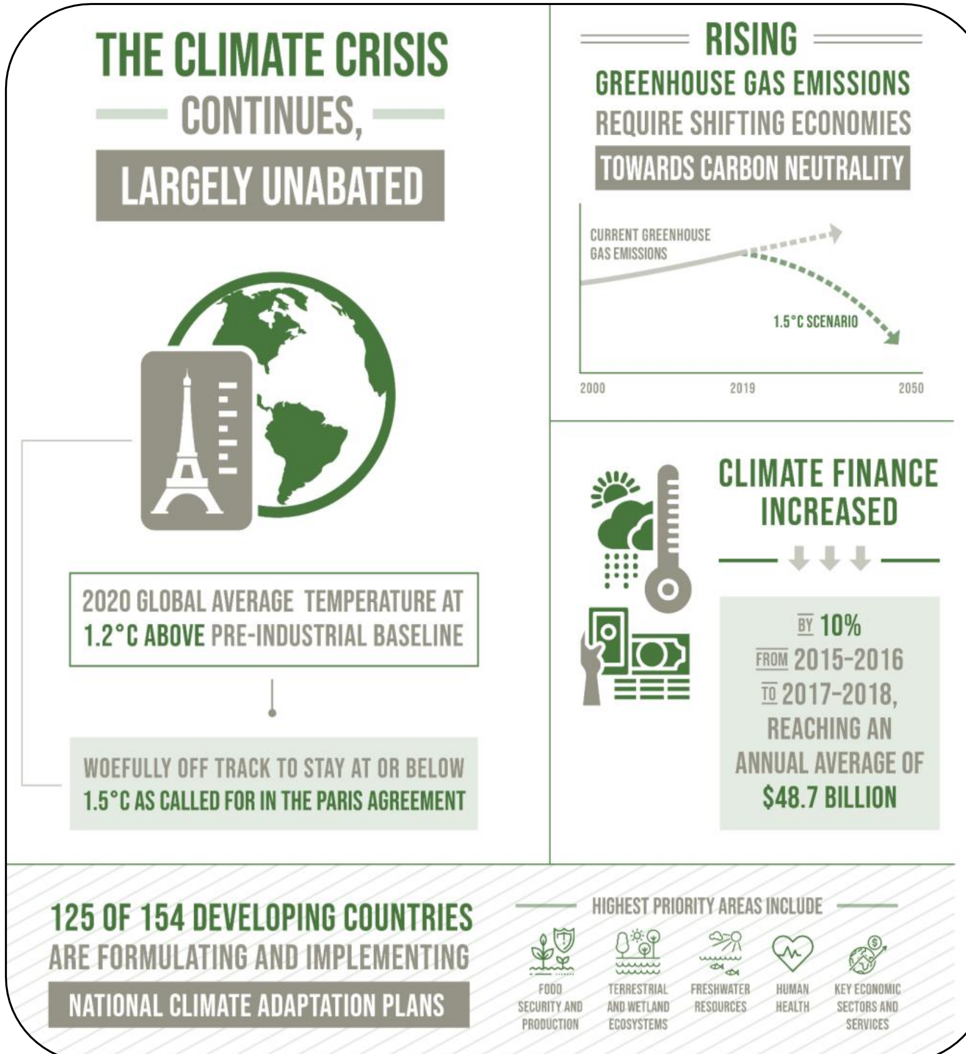
13 CLIMATE ACTION

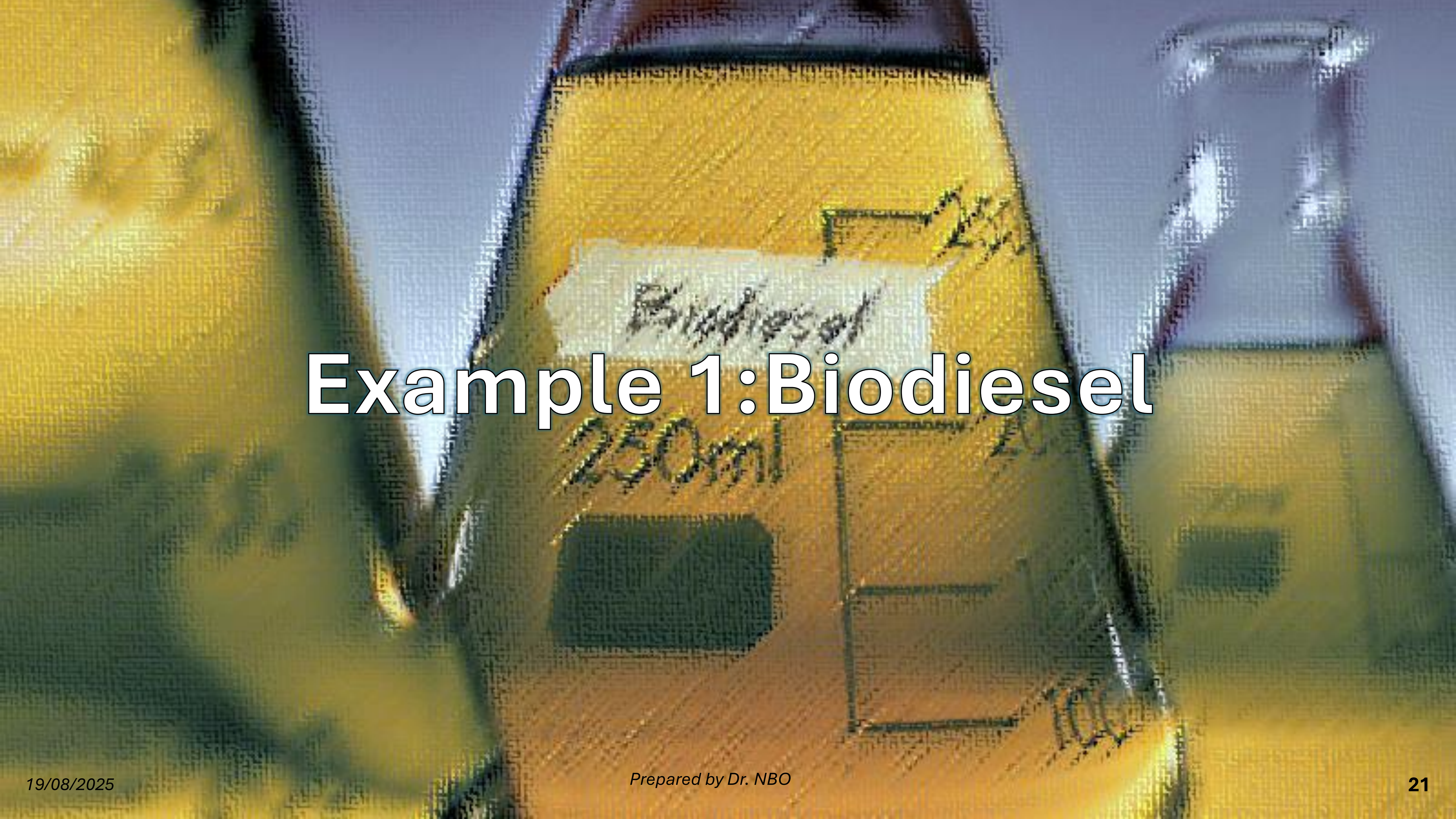
The Sustainable Development Goals (SDGs)

No. 7 Affordable and clean energy



No. 13 Climate Action





Example 1:Biodiesel

Overview of Biodiesel fuel

- Biodiesel is a fuel derived from biological sources (vegetables oil or animal fat) that has similarities to a diesel processed petroleum fuel.

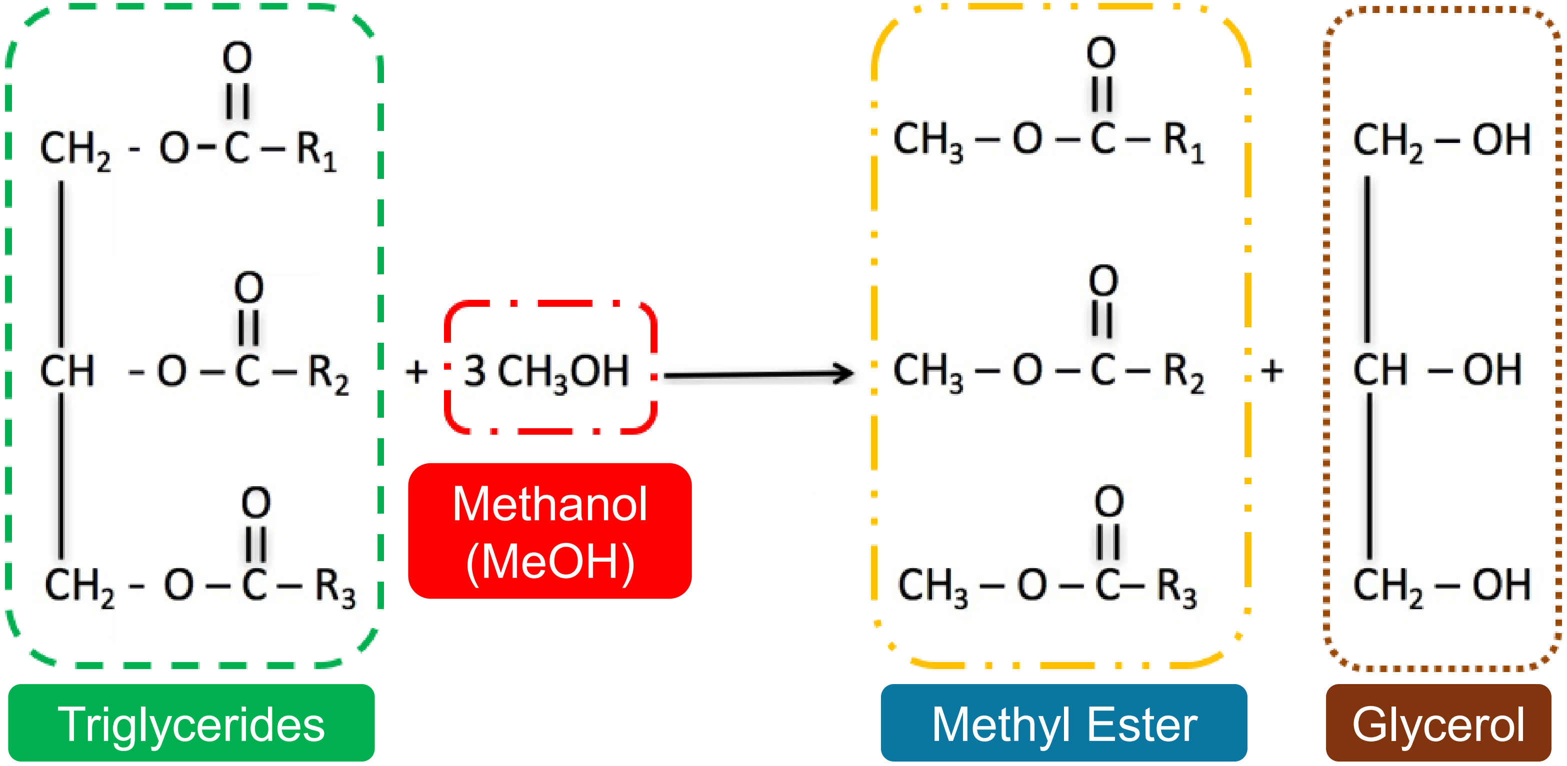
- Biodiesel is chemically defined as a fuel that comprises mono alkyl ester of long-chain fatty acid derived from renewable edible or non-edible lipid feedstock through the reaction with alcohol in the existence of a catalyst through transesterification process.

- Biodiesel can be used directly or blended with the Conventional Diesel Fuel (CDF). There are various standard specifications set by authorities/countries for commercial utilisation according to the set purposes. The American Standard and Testing Material (ASTM) D6751 is the well known standard for biodiesel blending with CDF while European Standard (EN) 14213 for net fuel usage (B100) as heating oil in fuel burner.

Biodiesel Production Method

Direct Blending	Supercritical Methanol	Transesterification	Pyrolysis/Thermal Cracking
❑ It is a simple process to synthesise biodiesel fuel ❑ Have high viscosity ❑ Bad volatility ❑ Bad stability characteristics	❑ No catalyst needed ❑ Short reaction time ❑ High conversion rate ❑ Good adaptability ❑ Need high temperature & pressure ❑ Expensive equipment ❑ High energy consumption	❑ Common & commercial method ❑ Easy to carry out ❑ Have economic benefits ❑ Require low temperature ❑ Reaction at atmospheric pressure ❑ Low cost ❑ High conversion rate ❑ Suitable for mass production	❑ A simple & non-polluting process ❑ Require high temperature ❑ Expensive equipment ❑ Has low purity

The Transesterification Process



❑Transesterification is a reaction process between vegetable oils or animal fats with alcohol (Methanol or Ethanol), in the present of catalyst (Acid or Alkaline), in order to separate alkyl esters and glycerol as by-products.

❑There are two types of transesterification, acid-based utilising acid catalyst such as Hydrochloric acid and Sulphuric acid and alkaline-based utilising base catalyst such as Potassium Hydroxide and Sodium Hydroxide.

❑This process depends on the Free Fatty Acid (FFA) content inside the feedstock, as high FFA content can react with the alkaline catalyst to form soap and reduce biodiesel yield. Determination of this content is by using titration method. Feedstock with high FFA above 2% require to undergo acid-based process to reduce FFA below 1% before alkaline-based transesterification is performed.

The Waste Cooking Oil

Cooking Oil


Frying for food preparation

Waste cooking oil

- Waste cooking oil is used as frying oil from vegetable oil or animal fats from the food preparation process.
- This oil usually being disposed after being used (once or several times) for cooking by any restaurants, caterers, food vendors, household, etc.
- The improper disposal of this oil into the drainage system cause sewer clogging problem and extinction of marine life.
- Repeated usage of cooking oil for frying degrades the oil due to high temperature heating, forming carcinogenic compounds such as hydroperoxides and polymerised triglycerides that can cause cancer in long-term usage.

Fuel Production

Determination of Free Fatty Acid

Edible

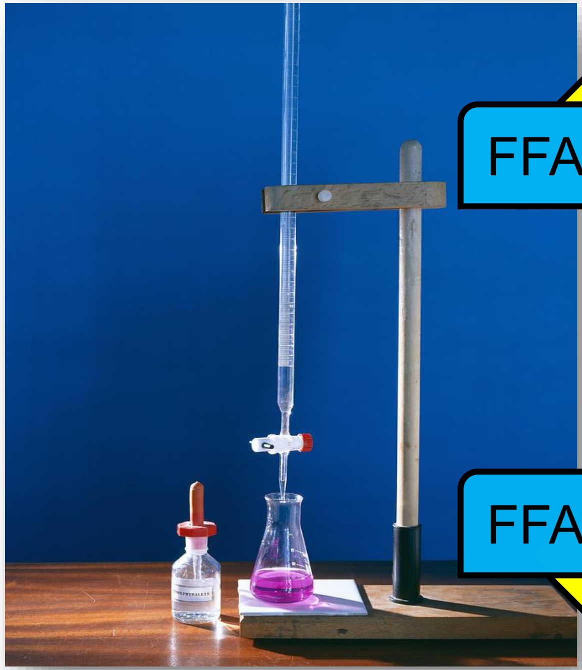
Coconut Oil

Palm Oil

Non-edible

Jatropha Oil

Waste Cooking Oil



Titration Method

FFA≥2% → Acid Catalysed Transesterification + Base Catalysed Transesterification

FFA≤2% → Base Catalysed Transesterification

Fuel Production

Acid Catalysed Transesterification – To reduce FFA

Non-edible

Jatropha Oil

Waste Cooking Oil

Amount of acid catalyst (H_2SO_4)	=1.5%v/v
Amount of Alcohol (MeOH)	=50%v/v
Reaction Temperature	=65°C
Reaction Time	=3hours
Stirring Speed	=400RPM

Separation 3 hours

Glycerol

Methyl Ester + Triglycerides

Methyl Ester & Triglycerides for Base Catalysed Transesterification

Fuel Production

Base Catalysed Transesterification – To produce Methyl Ester

Edible

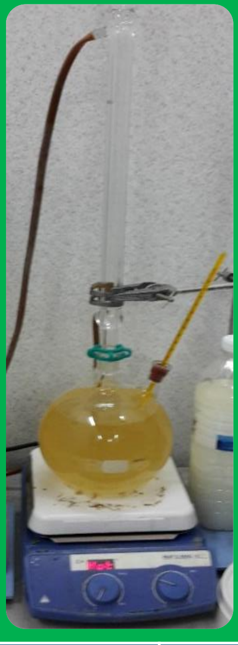
Non-edible

Palm Oil

Coconut Oil

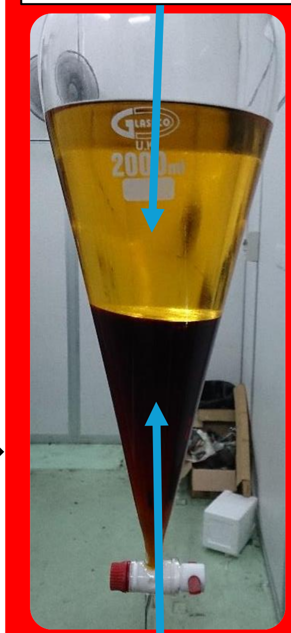
Jatropha Oil

Waste Cooking Oil



Amount of base catalyst (KOH)	=1.3%wt.
Amount of Alcohol (MeOH)	=25%v/v
Reaction Temperature	=60°C
Reaction Time	=1hours
Stirring Speed	=400RPM

Methyl Ester



Glycerol

Separation Overnight

Methyl Ester

Distilled Water

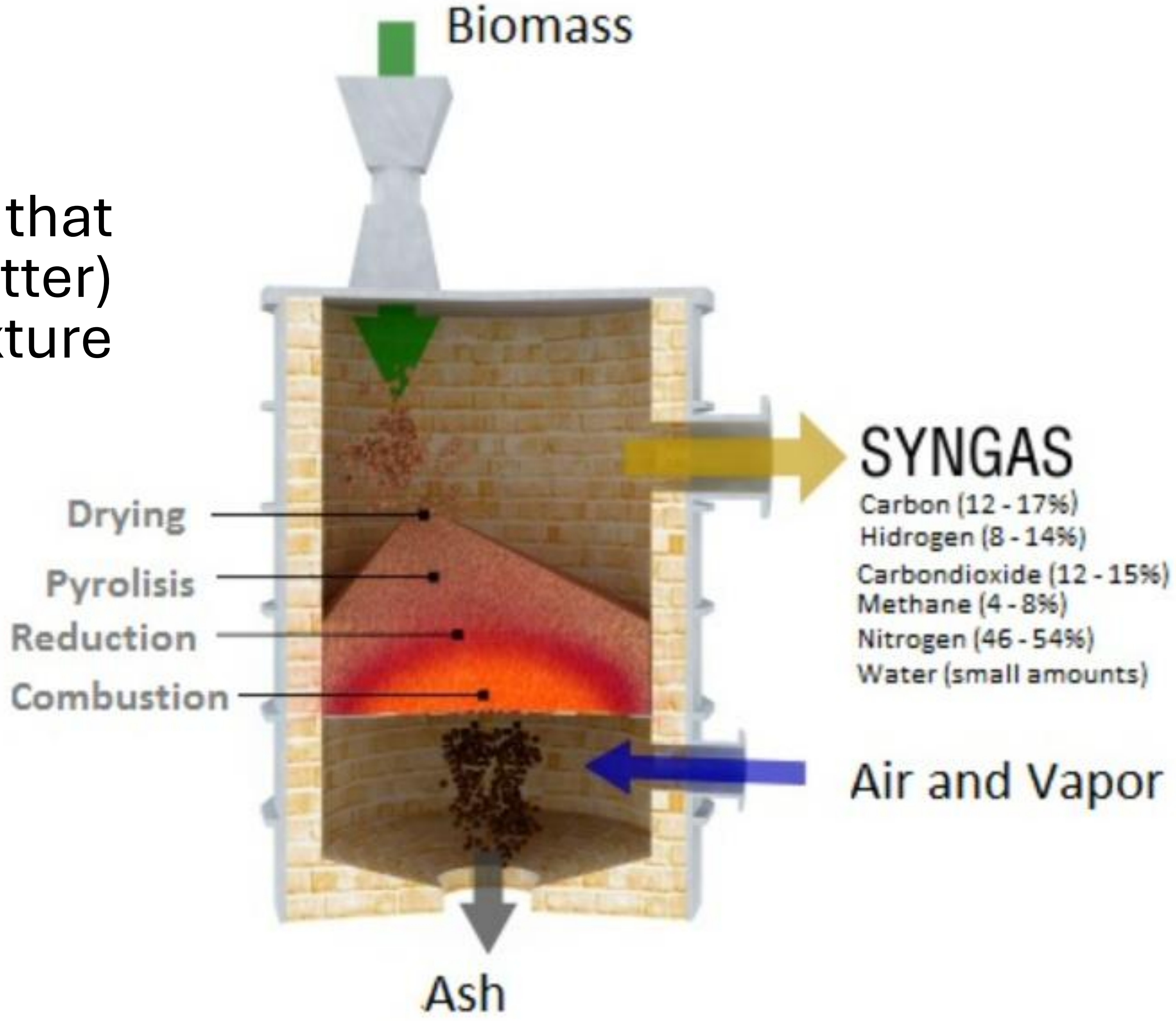
Wash a few times

Heated at 100°C for 1hour and let cool before blending

Example 2:Gasification

What is gasification?

- A thermochemical process that converts biomass (organic matter) into a combustible gas mixture called synthesis gas (syngas).



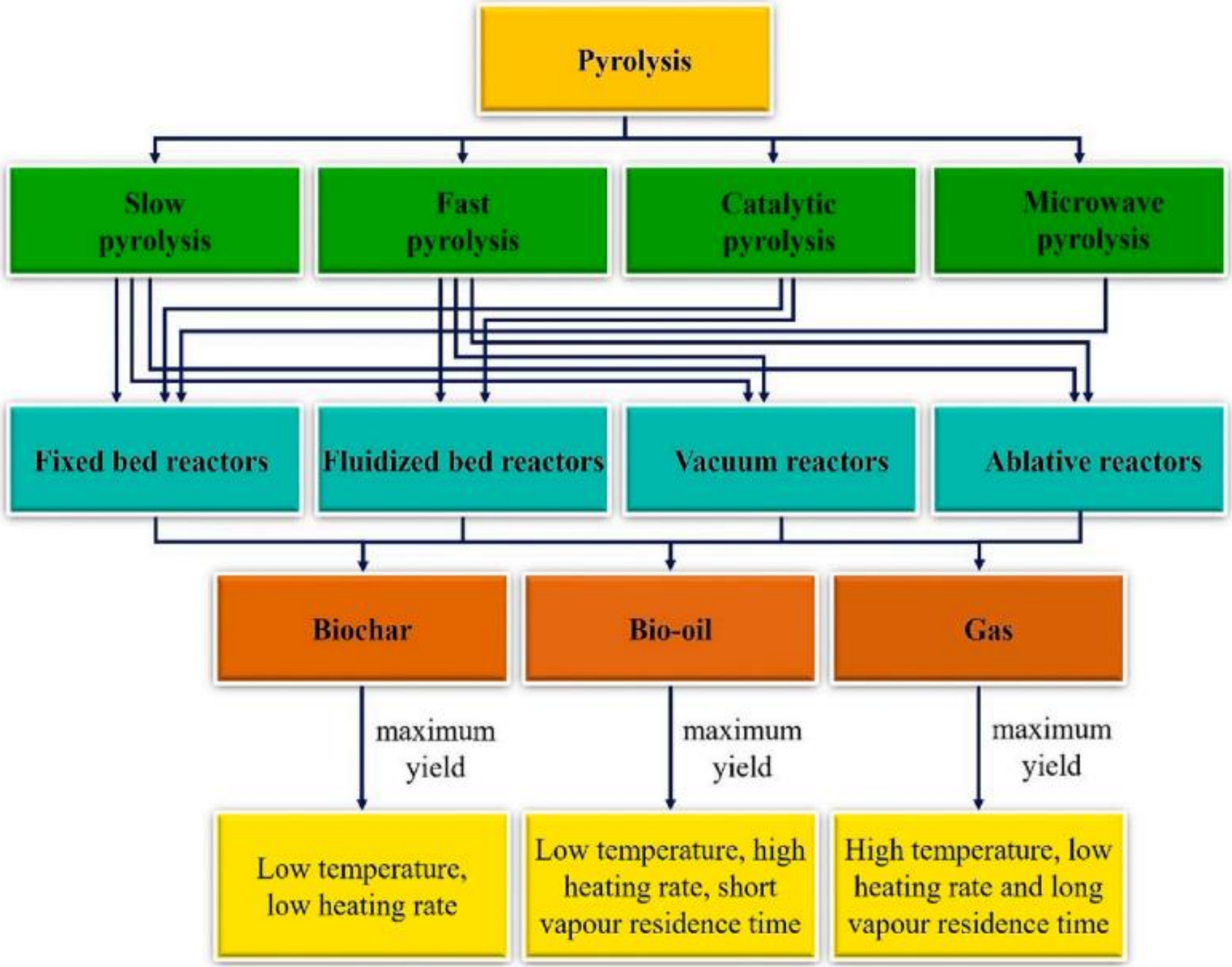
https://isaler.jimdofree.com/english/research-areas/gasification/

Full setup gasification test rig with monitoring system

Example 3:Pyrolysis of for Sustainable Aviation Fuel

What is pyrolysis?

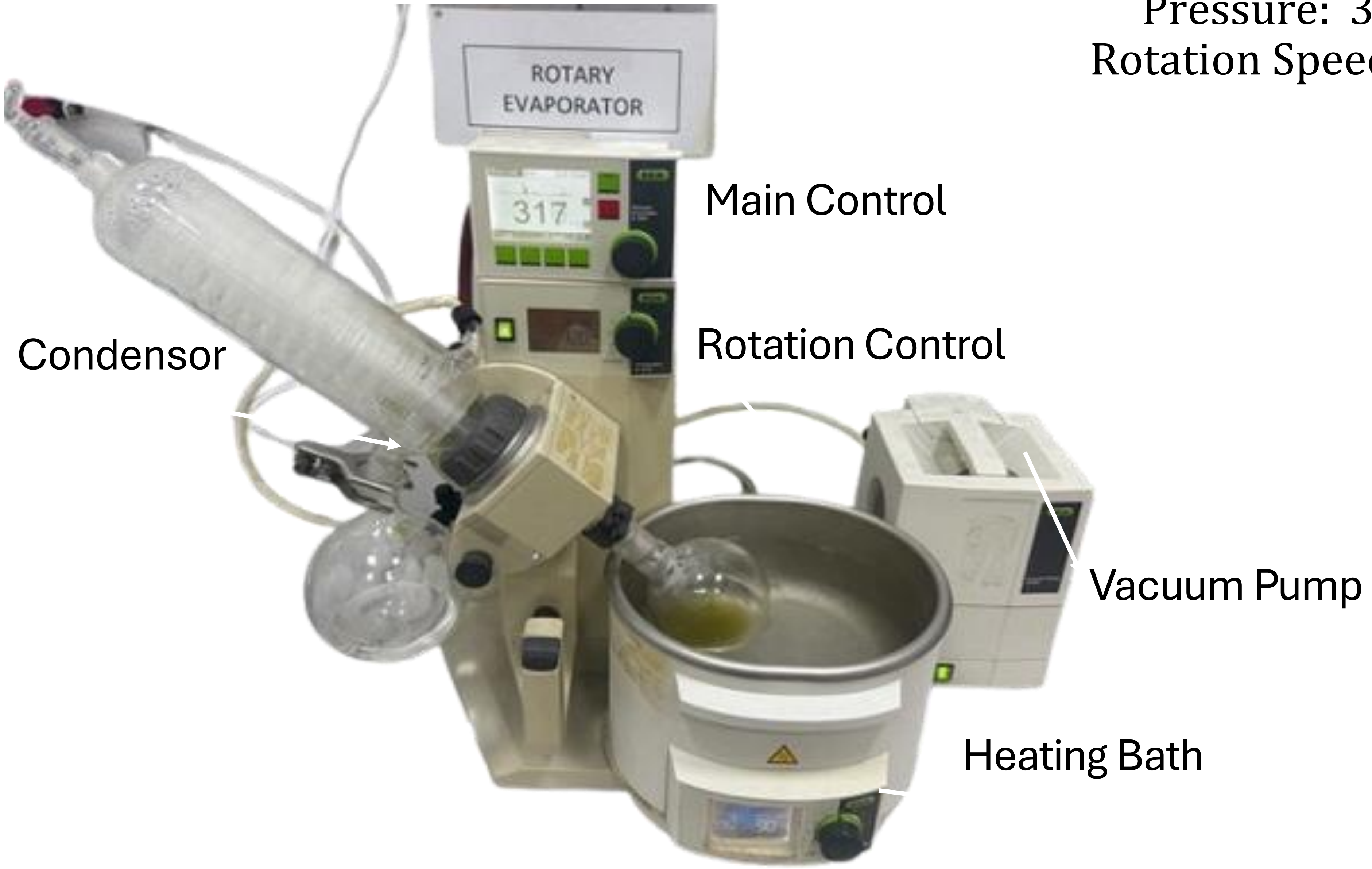
A thermochemical process that converts biomass into three main products: bio-oil, biochar, and pyrolysis gas, by heating the biomass in the absence of oxygen



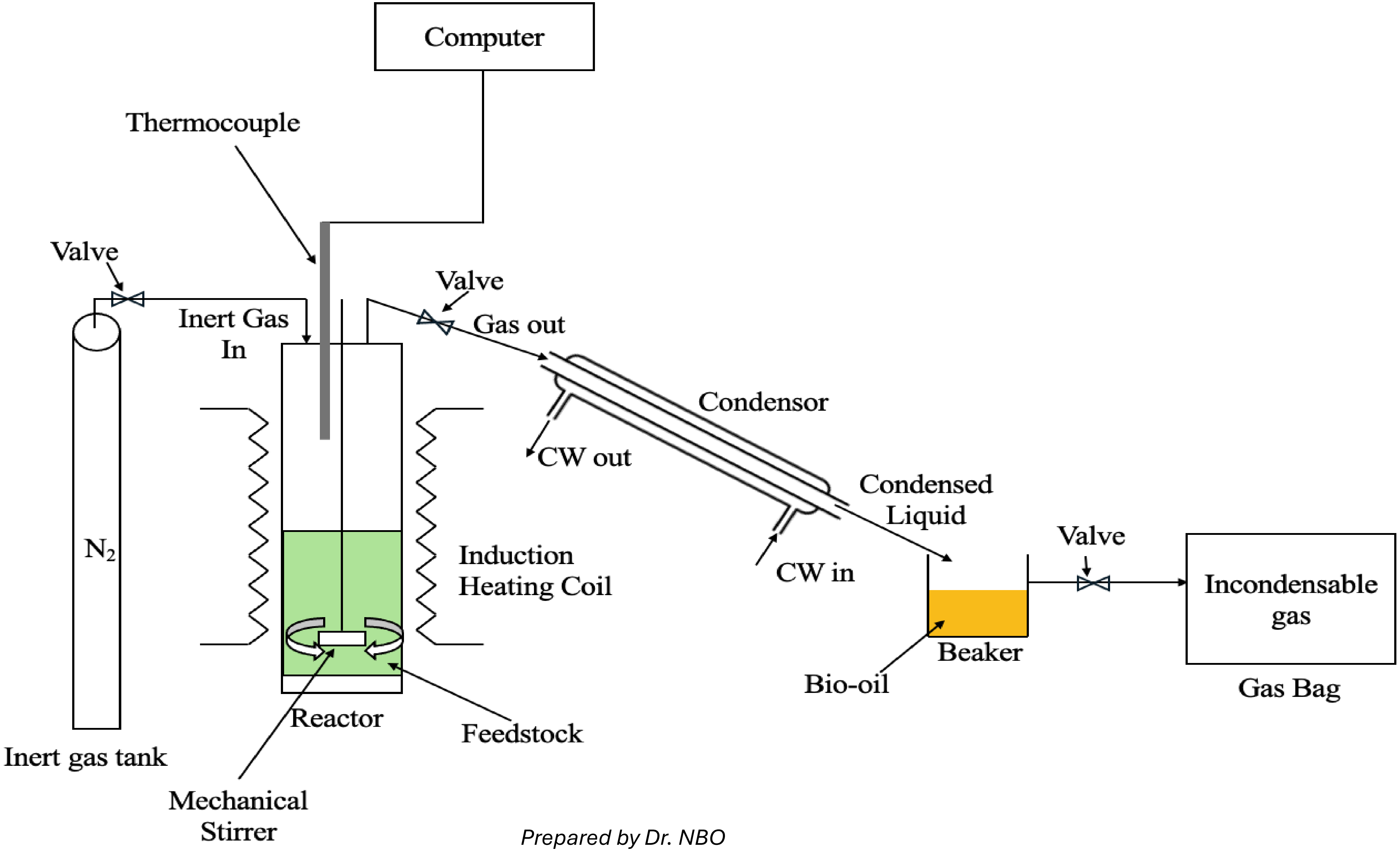
https://hal.science/hal-04198896v1/file/AgbulutMicroalgaeBioresourceTech2023revised.pdf

Drying of microalgae:

Water Bath Temperature: 90°C
Pressure: 304mbar
Rotation Speed: 120rpm



Pyrolysis Test Setup



Fuel Preparation

Biodiesel Fuel Blends

- The specific gravity (SG) of all blends was estimated using a linear graph plot
- CME, PME, JME & WCOME were mixed with CDF at the desired percentage blend
- SG for every blend was checked often using a hydrometer
- The blending process finish when SG constant & near estimation

Biodiesel Blends	Biodiesel Volume (Litre)	Diesel Volume (Litre)	Total Volume (Litre)
CME B5	0.5	9.5	10.0
PME B5			
JME B5			
WCOME B5			
CME B25	2.5	7.5	
PME B25			
JME B25			
WCOME B25			

Prepared by Dr. NBO

Biodiesel Physicochemical Properties

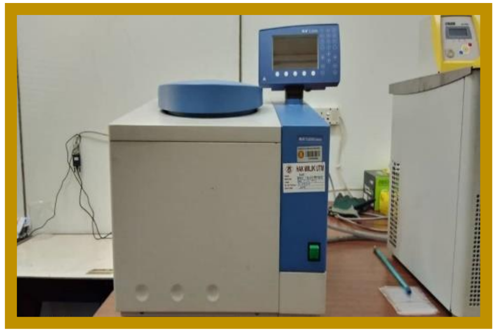
Density **Pycnometer**

Kinematics Viscosity
Townson+Mercer Viscometer

Cloud & Pour Point
SAMM Stanhope Seta Bath

Fatty Acid Composition
Agilent 19091S-433 Gas Chromatography Mass Spectrometry

Surface Tension
Kruss Tensionmeter



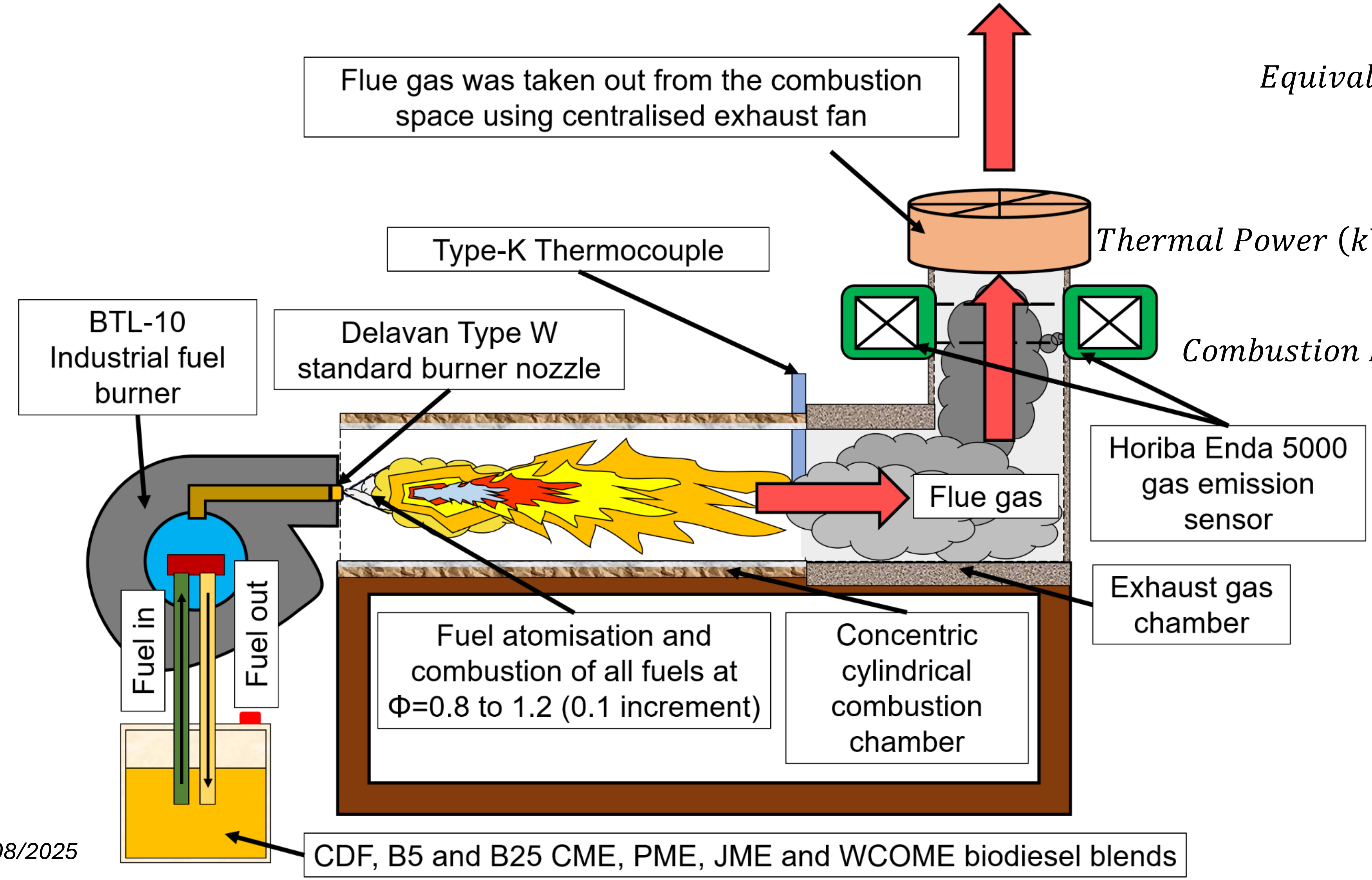
Gross Calorific Value
IKA C2000 Bomb Caloriemeter

Acid Value **Titration**

Flash Point
Anton Paar Pensky-Marten PMA5

Fuel Analysis

Evaluation of the Combustion and Emission

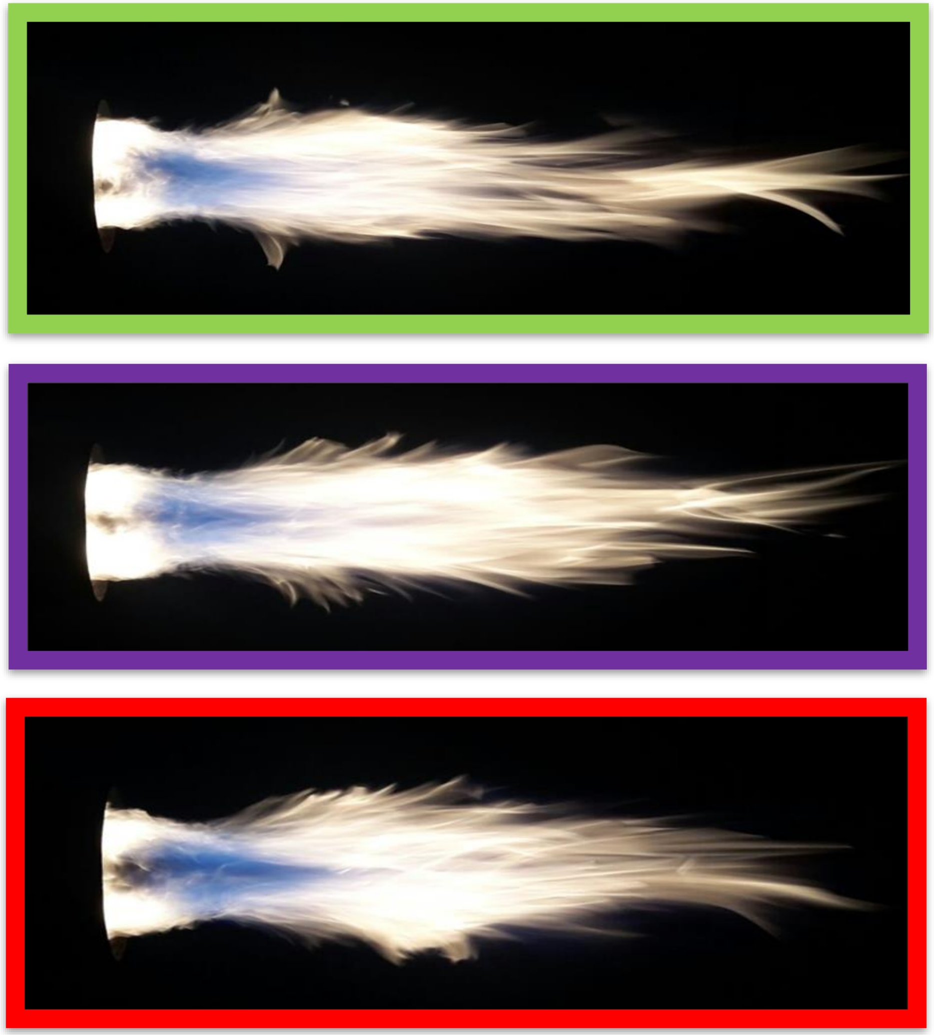


$$Equivalence\ Ratio, \Phi = \frac{\left(\frac{\dot{m}_{Fuel}}{\dot{m}_{Air}}\right)_{Actual}}{\left(\frac{\dot{m}_{Fuel}}{\dot{m}_{Air}}\right)_{Stoichiometry}}$$

$$Thermal\ Power\ (kW) = \frac{\dot{m}_{fuel} \times Gross\ Calorific\ Value}{3600}$$

$$Combustion\ Efficiency\ (\%) = \frac{CO}{CO + CO_2} \times 100\%$$

Biodiesel Combustion and Test Rig

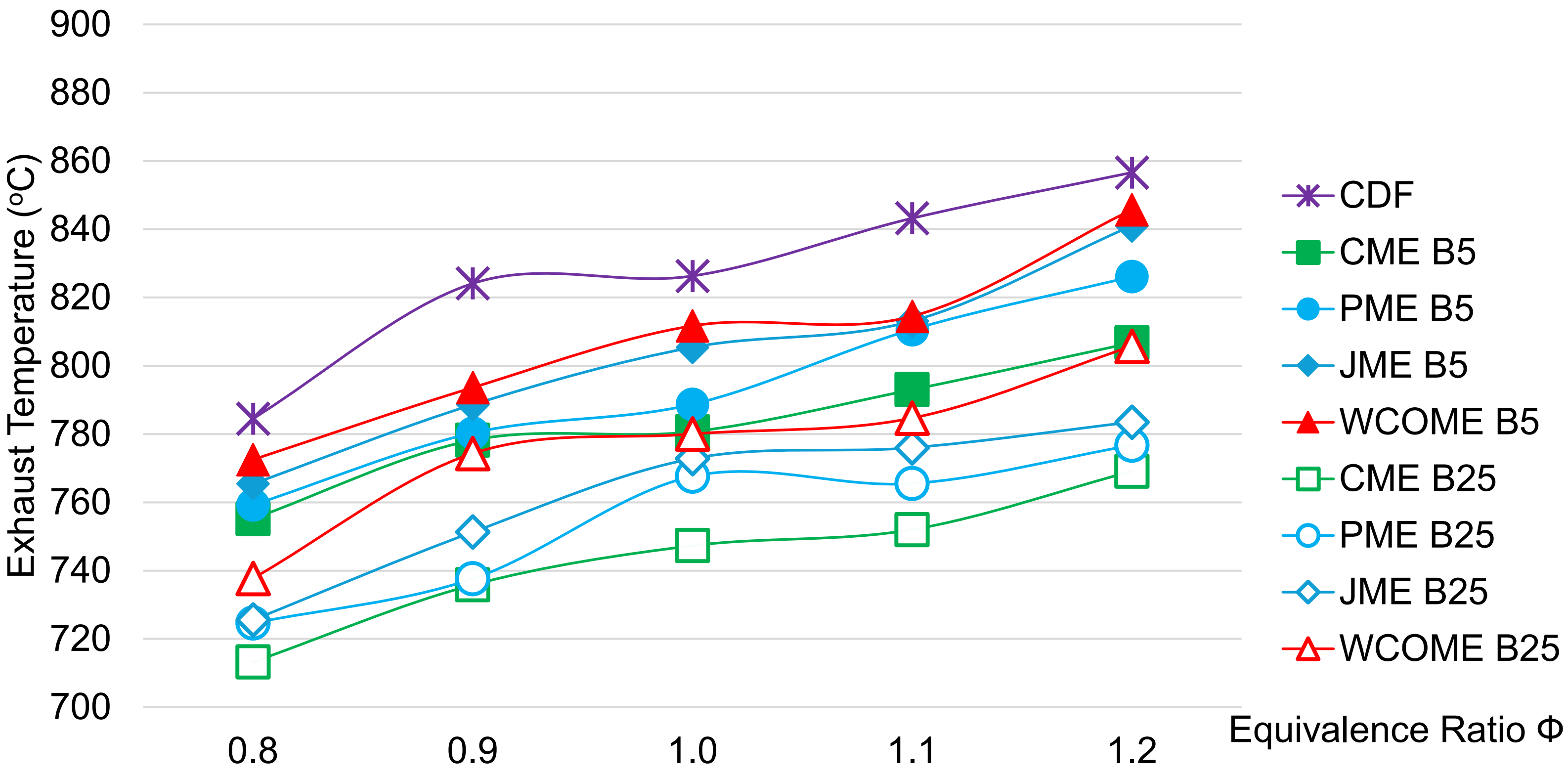


Flame observation inside the chamber

Gas turbine chamber

Emission Performance

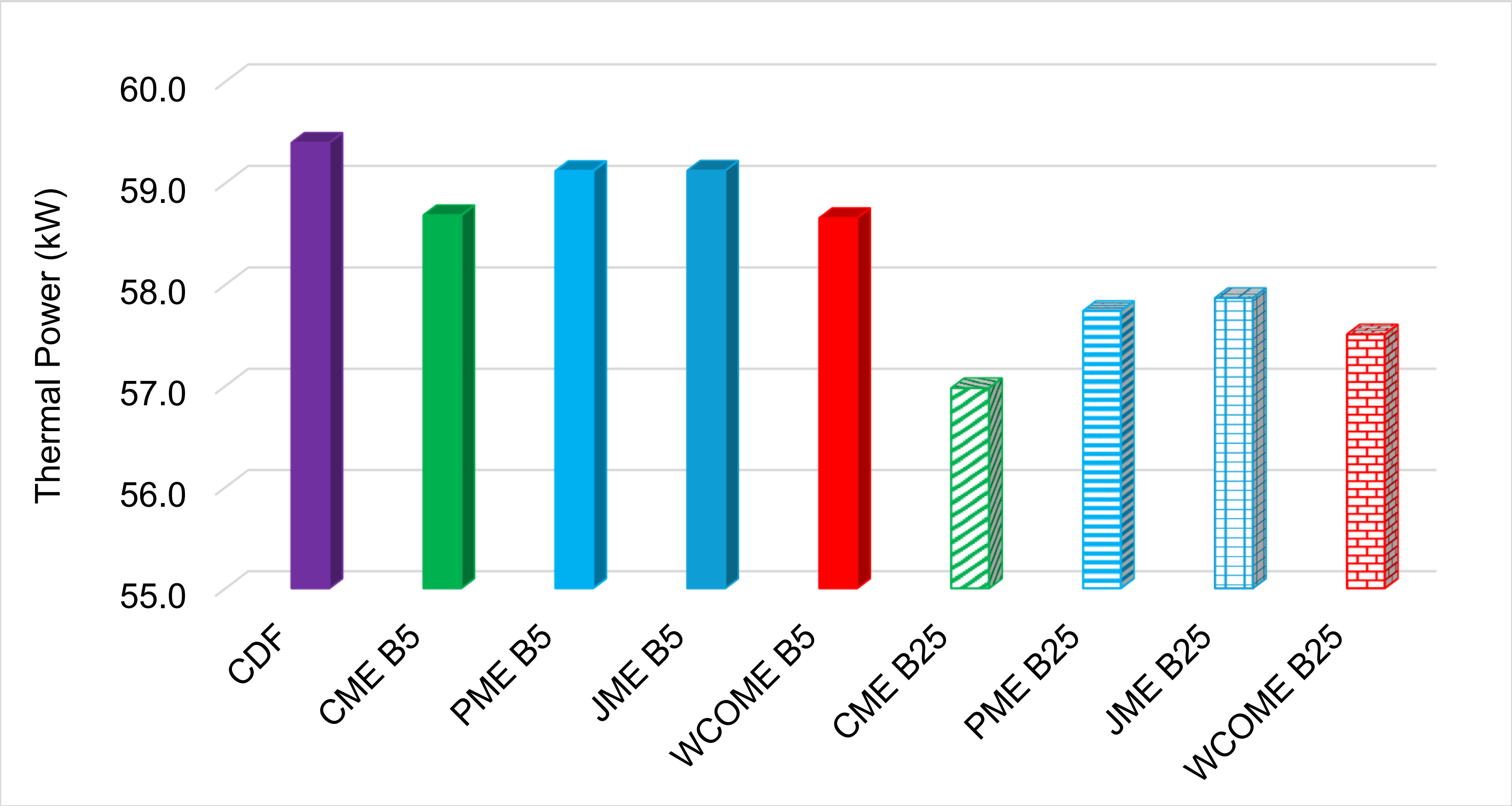
Exhaust Gas Temperature



- The exhaust gas temperature for all fuels are seen to increase from lean fuel to rich fuel mixture. This is due to all fuels are combust in excess proportion with reducing fuel supply that enhance greater exothermic heat release to the surrounding.
- Increasing all biodiesel content in the fuel blends will sequentially reduce the exhaust gas temperature than CDF, due to the reduction of gross calorific value, higher surface tension and kinematics viscosity. This affect fuel combustion from restriction on fine atomisation.
- Comparing every biodiesel blend, CME B25 biodiesel fuel combusts at the lowest temperature due to its high content of saturated fatty acid, than other feedstocks that combust at much lower temperatures than the rest of the biodiesel fuels that mainly contain unsaturated fatty acid.
- CDF generate the highest exhaust temperature as this fuel has the highest energy content.

Emission Performance

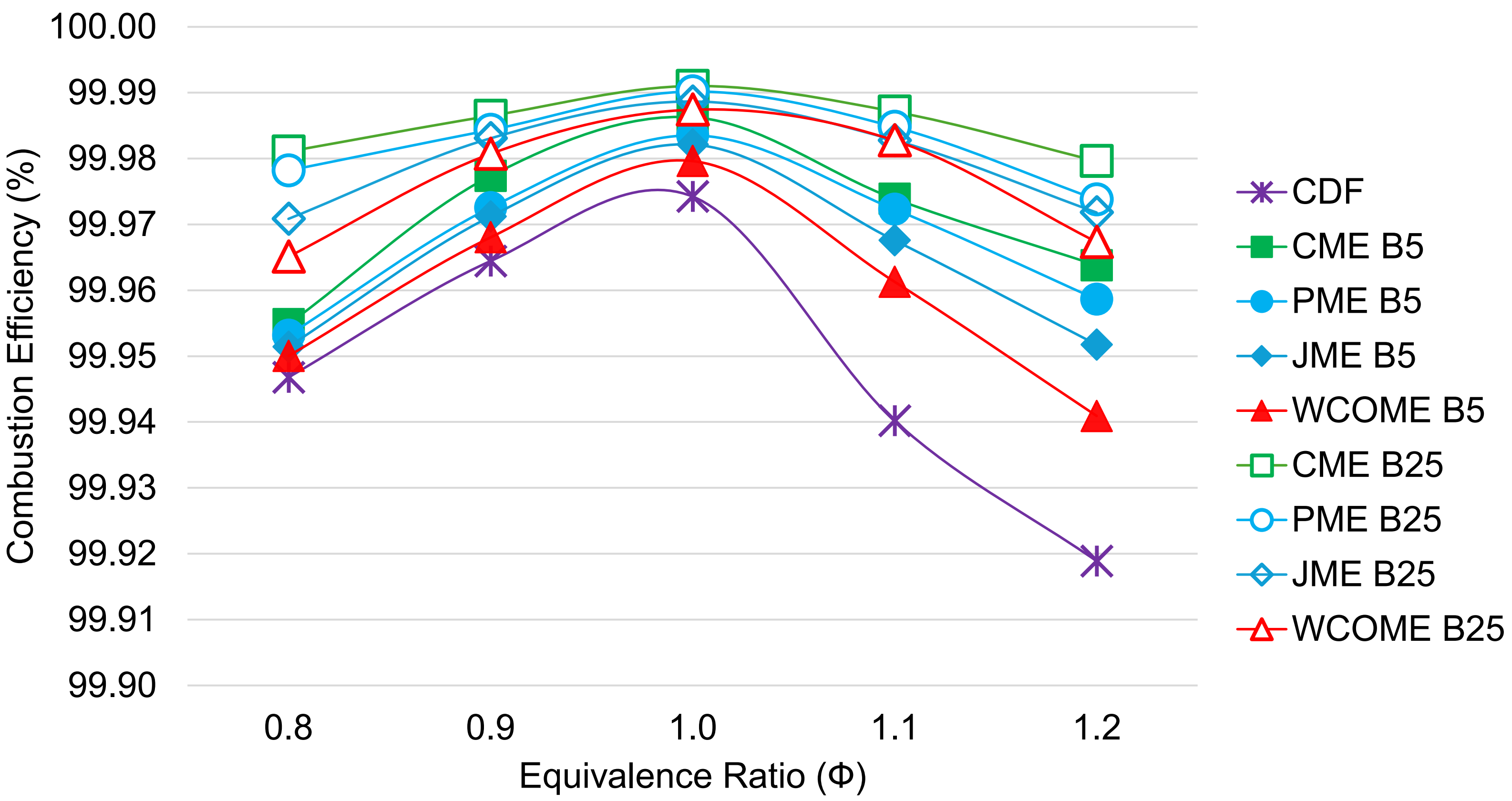
Thermal Power



- Increasing all biodiesel content in the fuel blends will sequentially reduce the thermal power, due to less fuel energy content than CDF.
- CME B25 biodiesel blend have the lowest thermal power than other biodiesel fuels due to its lowest calorific value than the rest.
- Although the exhaust gas temperature of WCOME B5 and B25 biodiesel blends is below CDF and above other biodiesel fuels due to its high content of unsaturated fatty acid than the rest, the thermal power are much lower than JME and PME biodiesel blends.
- This is due to much lower energy content and less dense than JME and PME biodiesel that reduce the fuel mass flow rate, amount of fuel combusted and eventually combustion temperature.

Emission Performance

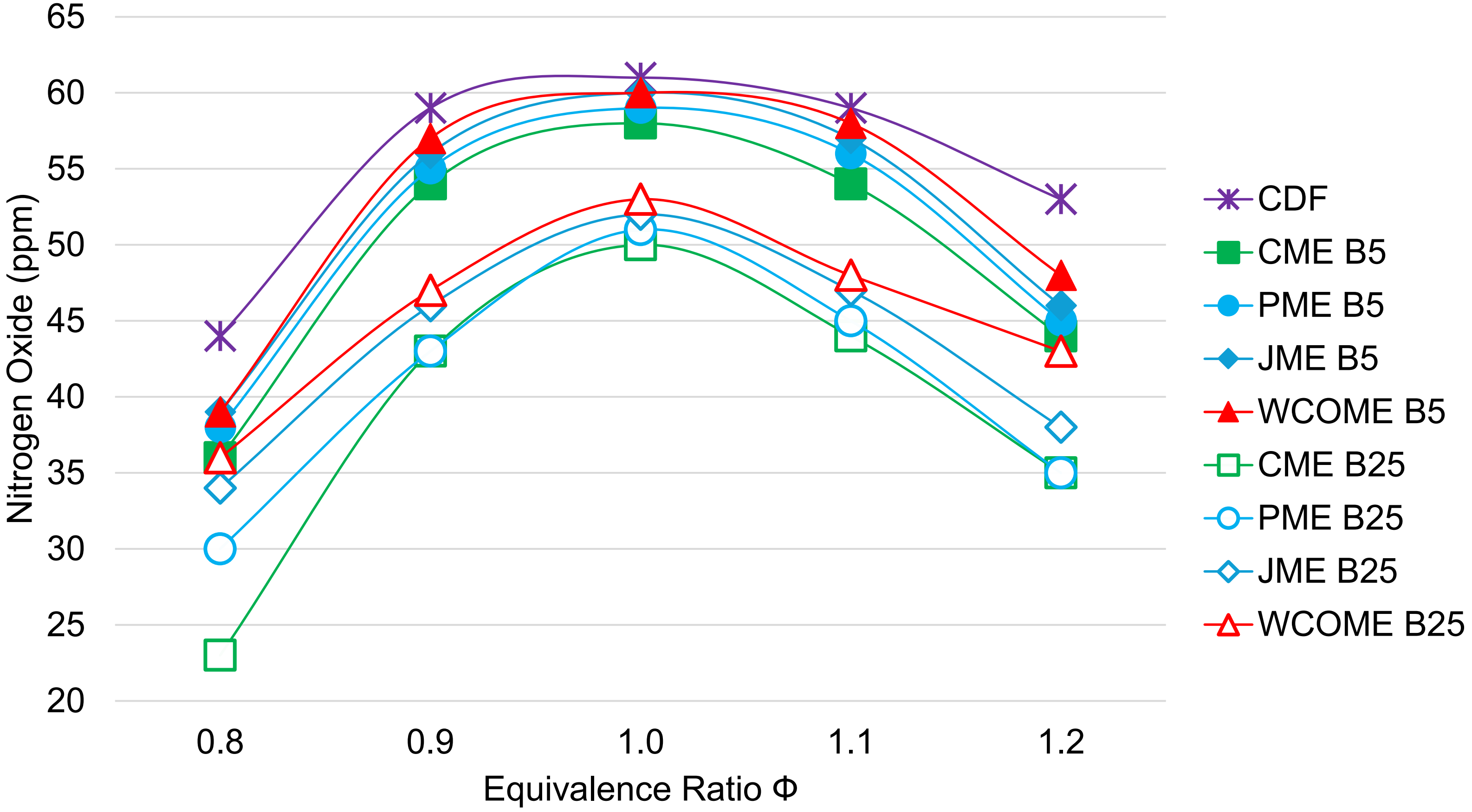
Combustion Efficiency



- ❑ The combustion efficiency is seen to increase towards stoichiometry due to a balance air to fuel mixture that aid complete combustion and generate low CO and high CO_2 emission.
- ❑ At rich fuel mixture where fuel is more than air, the combustion efficiency decrease due to high generation of CO, indicating the occurrence of incomplete combustion.
- ❑ Increasing all biodiesel content in the fuel blends will sequentially increase the combustion efficiency, due to improvement for complete combustion.
- ❑ This can be shown from less generation of CO and CO_2 of all biodiesel blends than CDF.
- ❑ CME B25 biodiesel blend is shown to combust the most efficient among other fuels due to its lowest CO and highest CO_2 generation across Φ.

Emission Characteristics

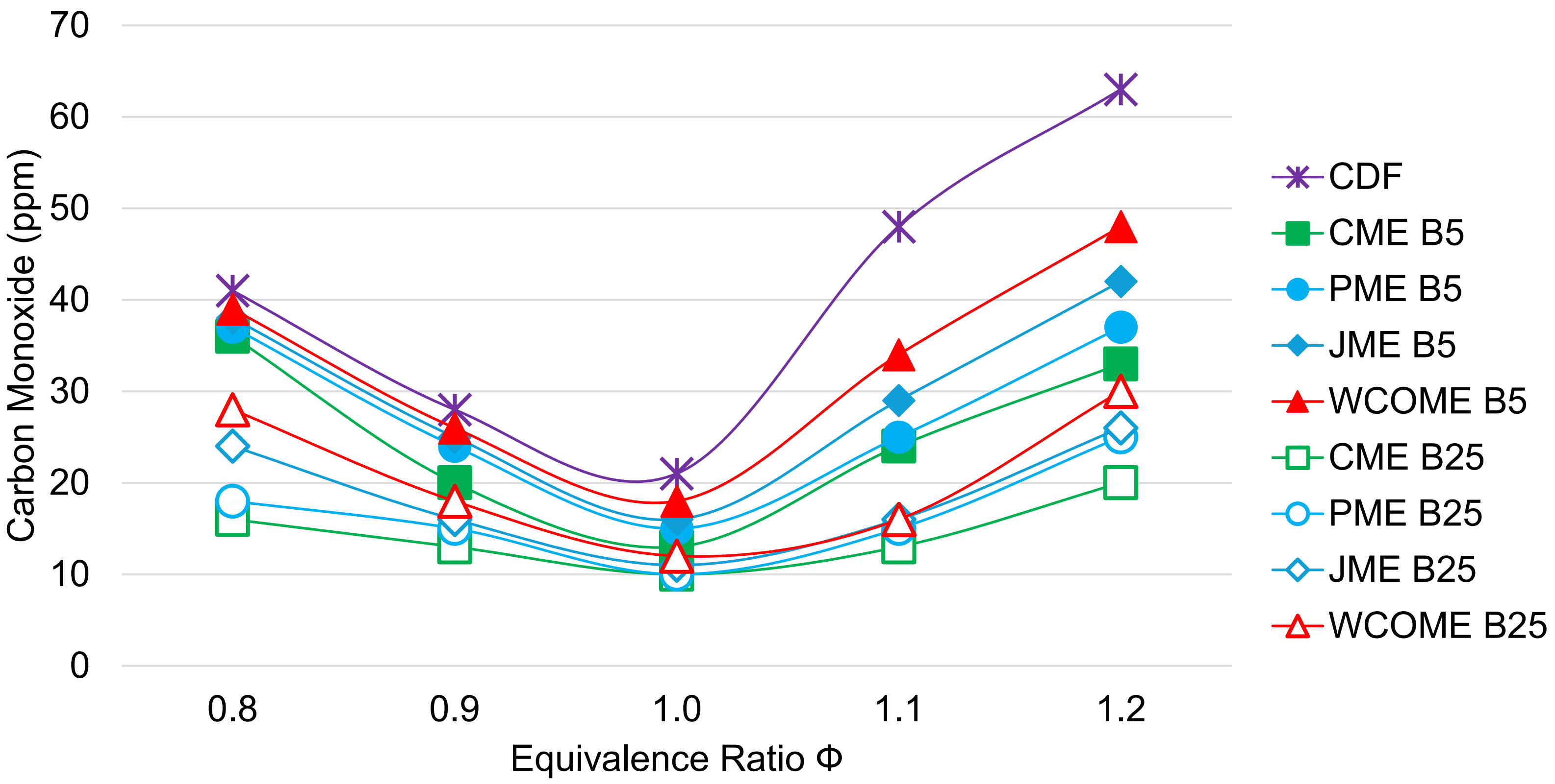
Nitrogen Oxide (NOx)



- The NO_X formation for all fuels are seen to increase towards stoichiometry due to availability of oxygen and increasing combustion temperature.
- However, the formation of NO_X is reduced in the rich fuel region due to reduction of oxygen content despite the combustion temperature is higher than in stoichiometry and lean mixture.
- Increasing all biodiesel content in the fuel blends will sequentially reduce NO_X, due to enhancement on combustion at lower temperature from low heat release rate.
- CME B25 biodiesel blend is shown to generate the least NO_X among other biodiesel feedstock. This is because of its high composition of saturated and medium chain length fatty acid structure that reduce the combustion flame temperature to be less than the rest.

Emission Characteristics

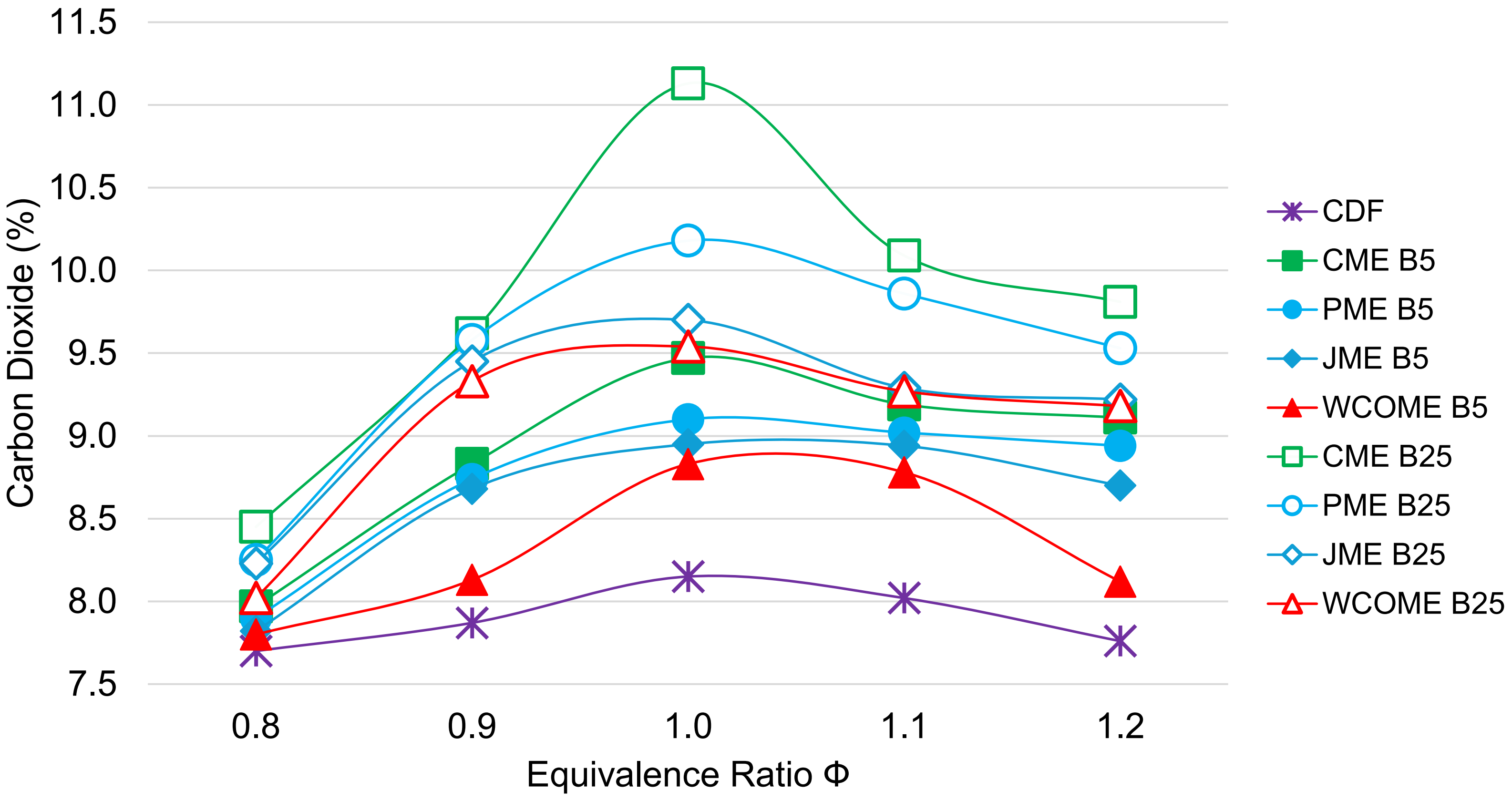
Carbon Monoxide (CO)



- The CO formation for all fuels are seen to reduce towards stoichiometry due to a balance condition that promote complete fuel to air mixture during combustion.
- The formation of CO increase in the rich fuel region due to great amount of fuel is burned in low air surrounding, resulting incomplete combustion.
- Increasing all biodiesel content in the fuel blends will sequentially reduce CO, due to its high oxygen content that improve combustion rate and eventually promote the reduction of CO.
- CME B25 biodiesel blend is shown to generate the least CO among other biodiesel feedstock due to its properties of having the least value on kinematics viscosity and surface tension. Both properties make the fuel to atomise better than the rest of the fuel, thus improving combustion and eventually reduce CO emission.

Emission Characteristics

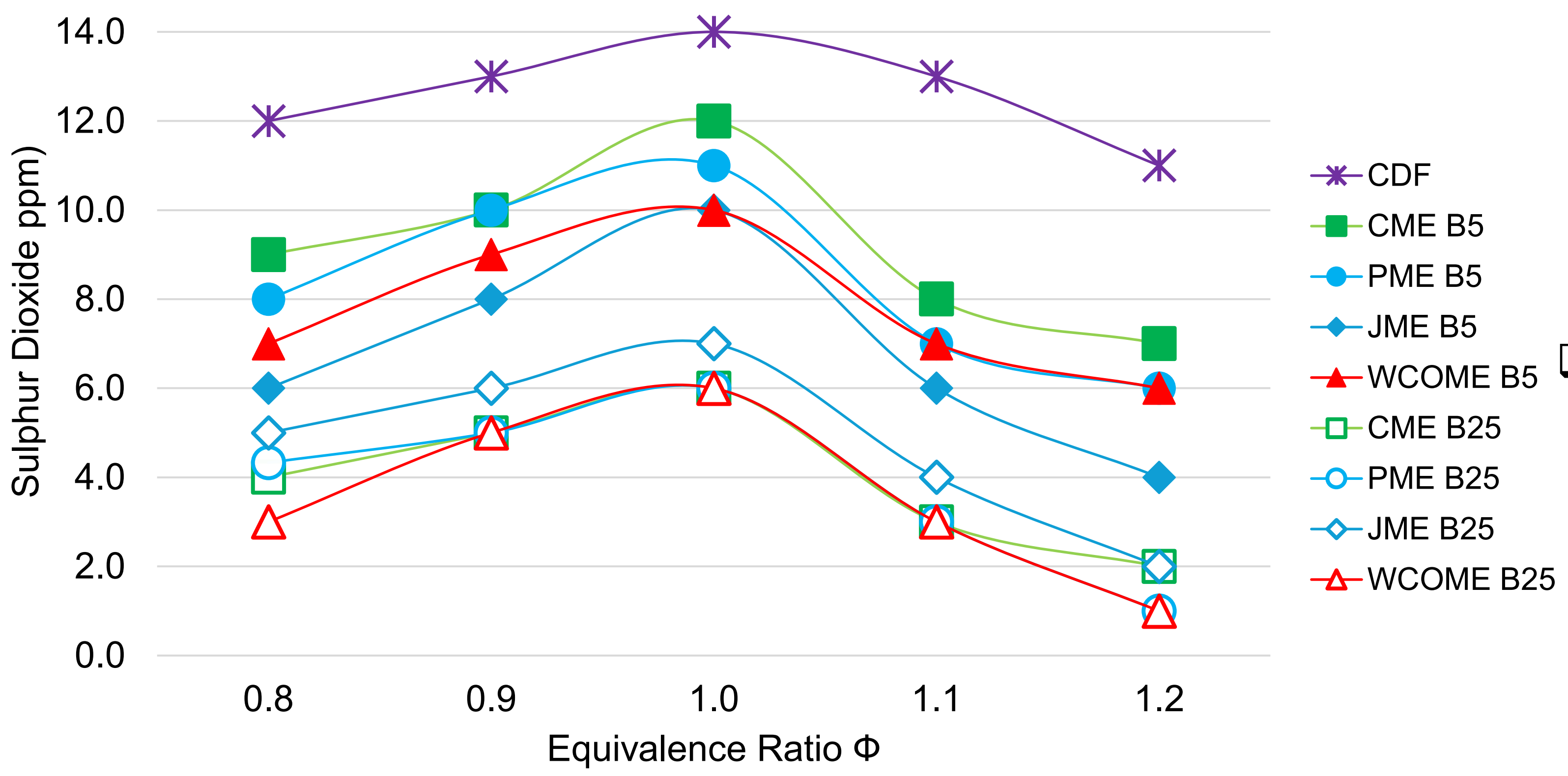
Carbon Dioxide (CO_2)



- The CO_2 formation for all fuels are seen to increase towards stoichiometry due to a balance condition that promote complete fuel to air mixture and combustion.
- The formation of CO_2 decrease in the rich fuel region due to great amount of fuel is burned in low air surrounding, resulting incomplete combustion that promote CO.
- Increasing all biodiesel content in the fuel blends will sequentially increase CO_2 formation due to improvement on the fuel combustion rate and reduction of rich fuel region, thus promoting conversion of CO to CO_2.
- CME B25 biodiesel blend is shown to generate the highest CO_2 among other biodiesel feedstocks due to better promotion of the fuel for complete combustion that eventually aids CO conversion to CO_2.

Emission Characteristics

Sulphur Dioxide (SO2)



- The SO_2 formation for all fuels are seen to increase towards stoichiometry due to an increasing combustion temperature and presence of enough air that promote reaction between sulphur and hydrogen molecules in the fuel and sulphur and surrounding oxygen to form SO_2.

- The formation of SO_2 is seen to decrease in the rich fuel region due to reduction of presence air that suppress the reaction of sulphur and oxygen to form SO_2 despite the combustion temperature is higher than stoichiometry and lean fuel mixture.

- Increasing all biodiesel content in the fuel blends will sequentially reduce SO_2 formation due to the nature of biodiesel itself that contains very less or no sulphur at all. Blending with fossil fuel will dilute the sulphur content and reduce SO_2 formation.

Conclusion

- Emissions can be reduced by changing the fossil fuel with the alternative fuel.
- Transesterification, gasification and pyrolysis are a few methods that can convert the variation of the feedstock to the alternative fuel.
- The alternative fuel physical properties of all biodiesel blends/alternative fuels were measured in terms of density, kinematic viscosity, surface tension and gross calorific value.
- Syngas can potentially be an alternative for the power source and byproduct.
- Alternative fuel offers a wide range of potential applications, from waste-to-energy.

ご清聴ありがとうございました

Q & A

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