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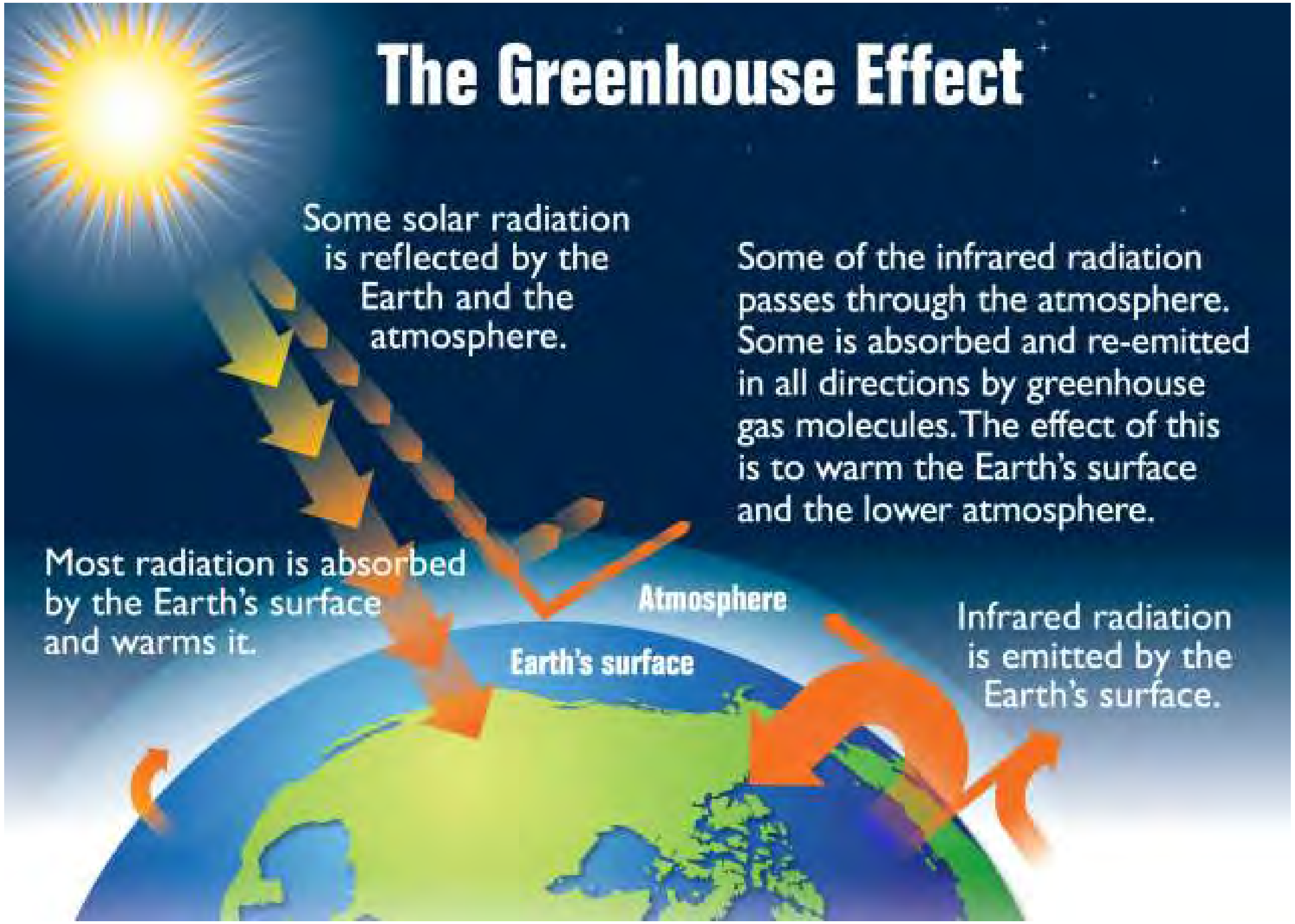
Introduction to Advanced Internal Combustion Engine and Potential of Waste Plastic Fuel for Myanmar

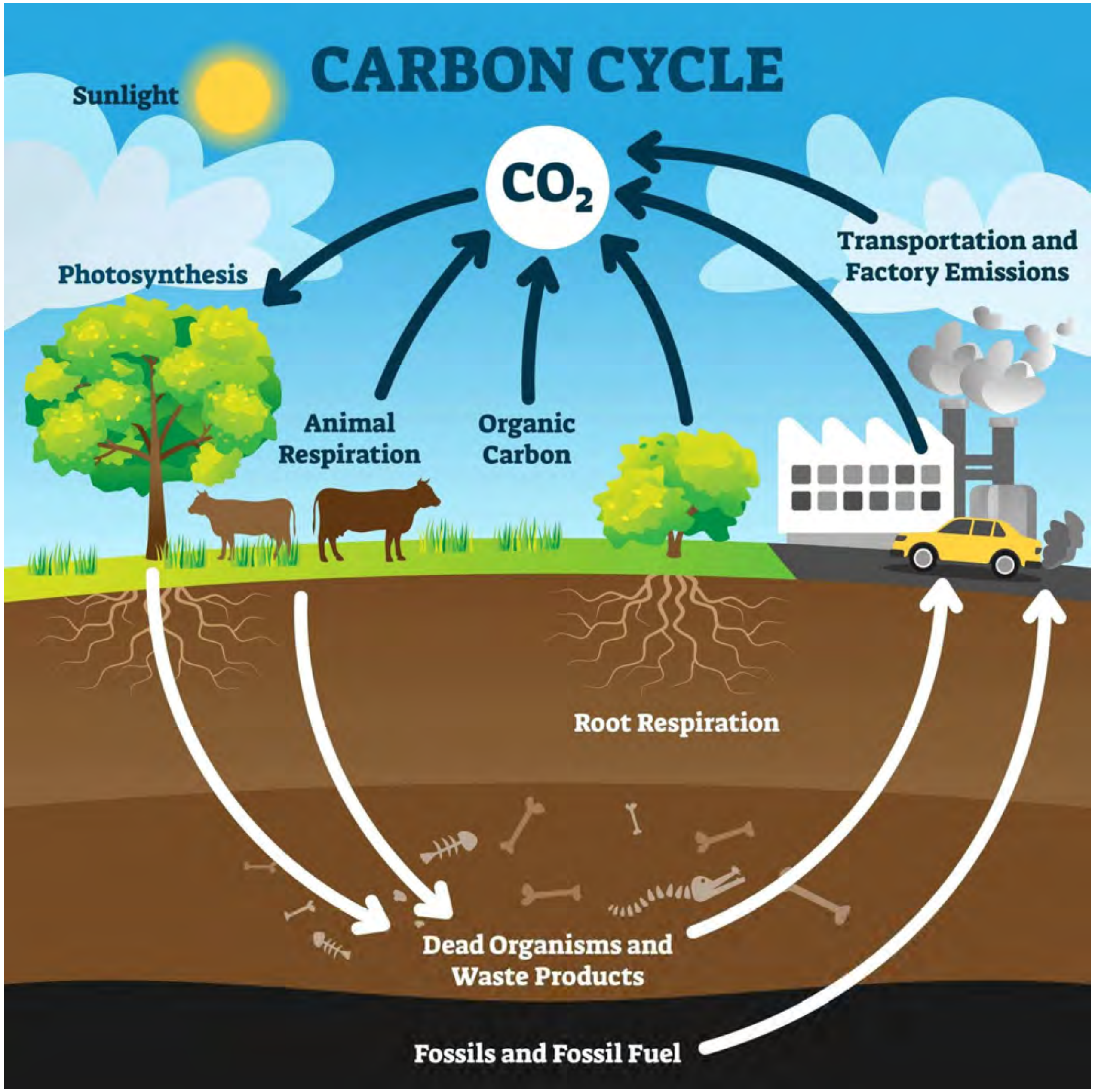
By
Dr. Zin Thu Aung
Lecturer
Ph.D.(Mechanical)Thailand
TVET Teacher Training Center(Baelin)
Ministry of Science and Technology

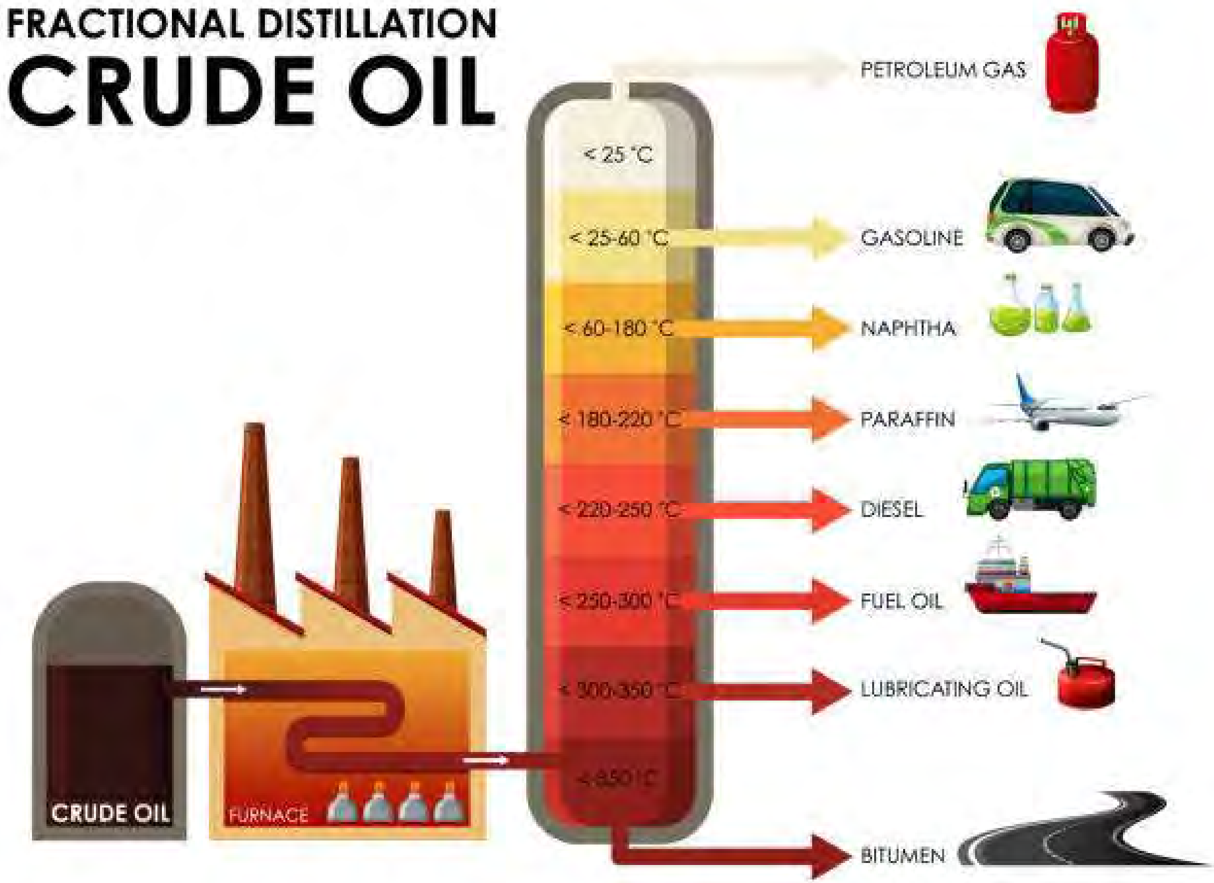
25/05/2024

Introduction

Global Warning and Energy Demand

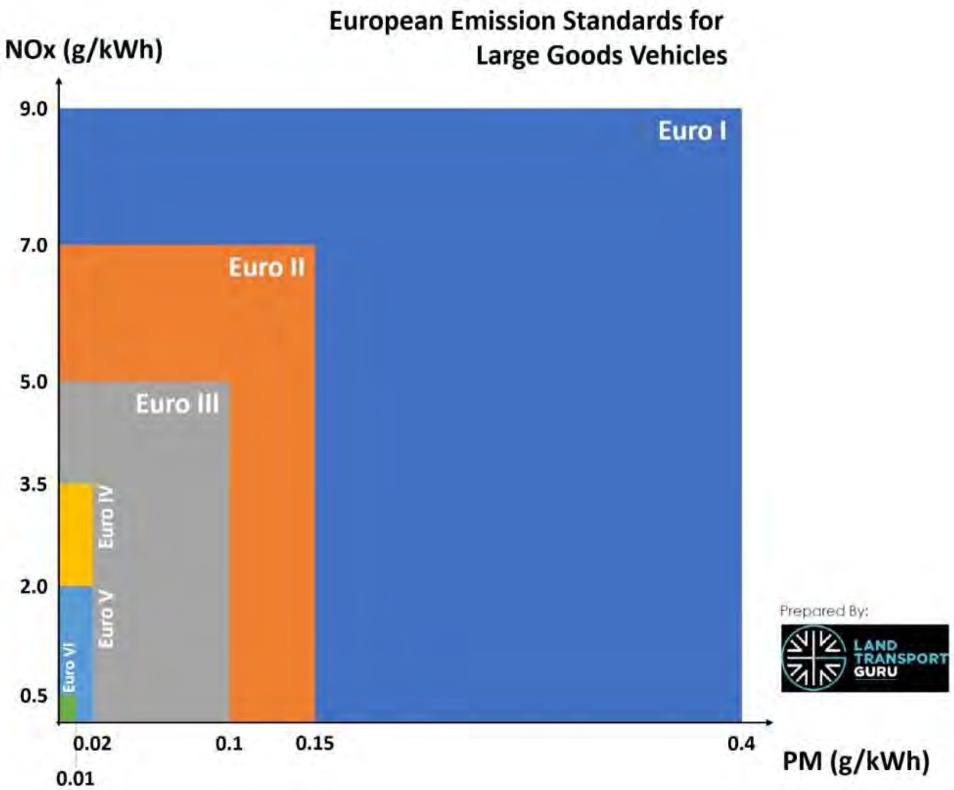

The Greenhouse Effect
Some solar radiation is reflected by the Earth and the atmosphere.
Some of the infrared radiation passes through the atmosphere. Some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.
Most radiation is absorbed by the Earth's surface and warms it.
Atmosphere
Earth's surface
Infrared radiation is emitted by the Earth's surface.

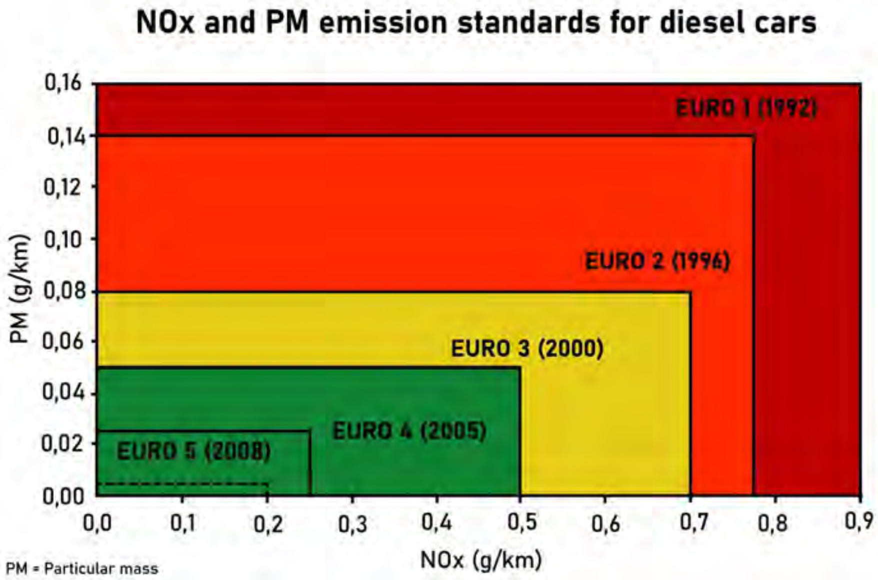

CARBON CYCLE
Sunlight
CO_2
Photosynthesis
Transportation and
Factory Emissions
Animal
Respiration
Organic
Carbon
Root Respiration
Dead Organisms and
Waste Products
Fossils and Fossil Fuel



FRACTIONAL DISTILLATION
CRUDE OIL
< 25 °C
< 25-60 °C
< 60-180 °C
< 180-220 °C
< 220-250 °C
< 250-300 °C
< 300-350 °C
< 350 °C
PETROLEUM GAS
GASOLINE
NAPHTHA
PARAFFIN
DIESEL
FUEL OIL
LUBRICATING OIL
BITUMEN
CRUDE OIL
FURNACE

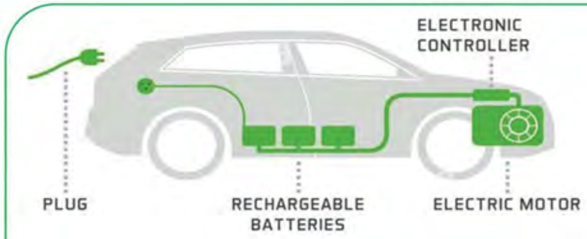
Emission Standard (Euro and Tier)





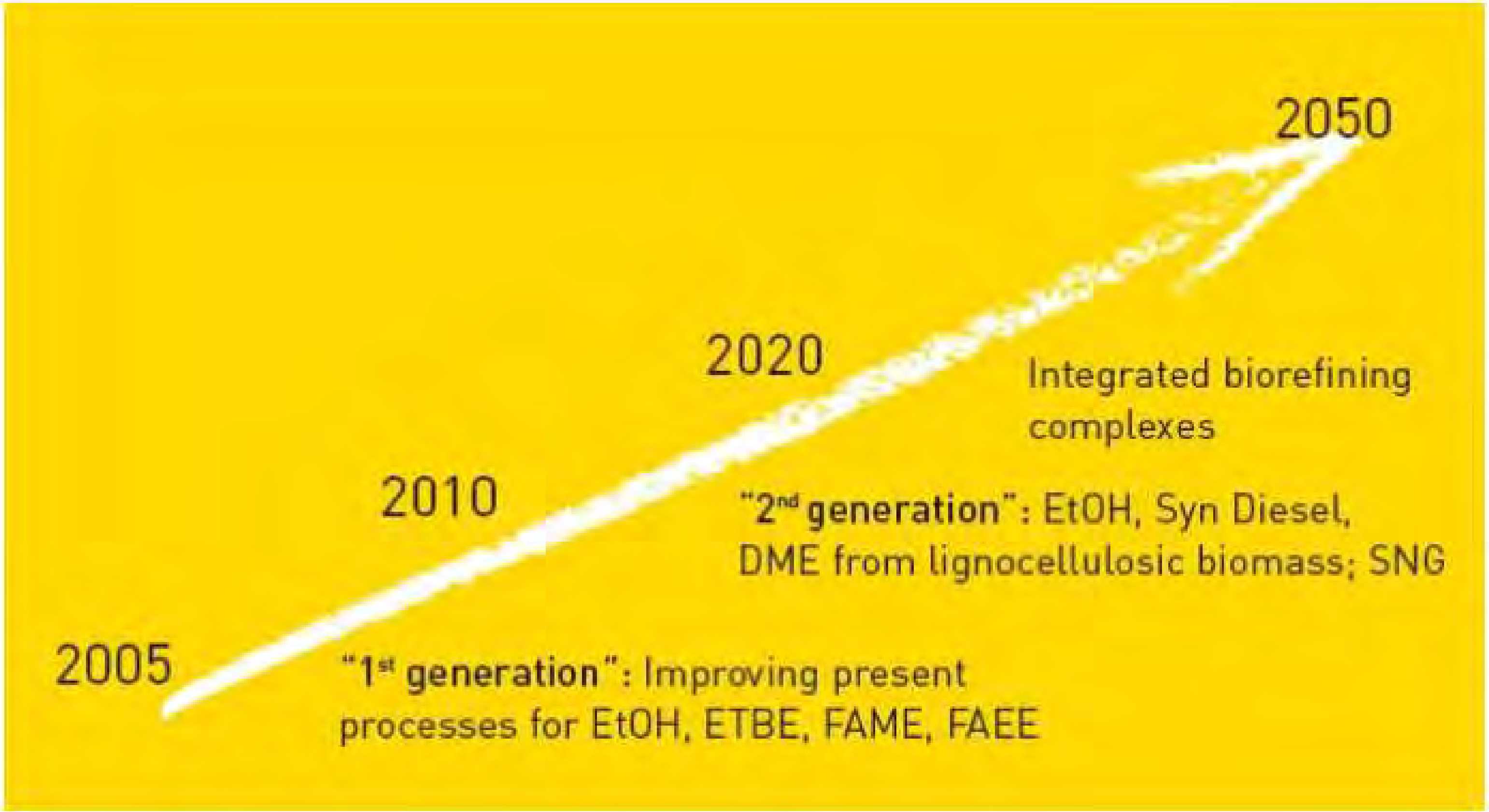
Go Green with Electric Vehicles

- ❖Green Energy
- ❖Zero Emission
- ❖Easy Maintenance
- ❖Less Noise
- ❖Safe Money



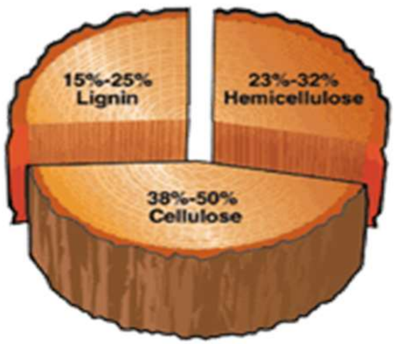
Electric Vehicle (EV)	Internal Combustion Engine (ICE) Vehicle
Battery to wheel efficiency above 80-90%	❖Tank to wheel efficiency below 25%
24 moving parts	❖150 moving parts
11 wearing parts	❖24 wearing parts
High Torque at low RPM	❖High torque at specific RPM range
No Tailpipe Emisssions	❖ Greenhouse Gases/Pollution
100+/- Mile Range	❖ 300+ Mile Range
Hours to Recharge	❖ Minutes to Refuel
50mmk per mile	❖ 300mmk + per mile

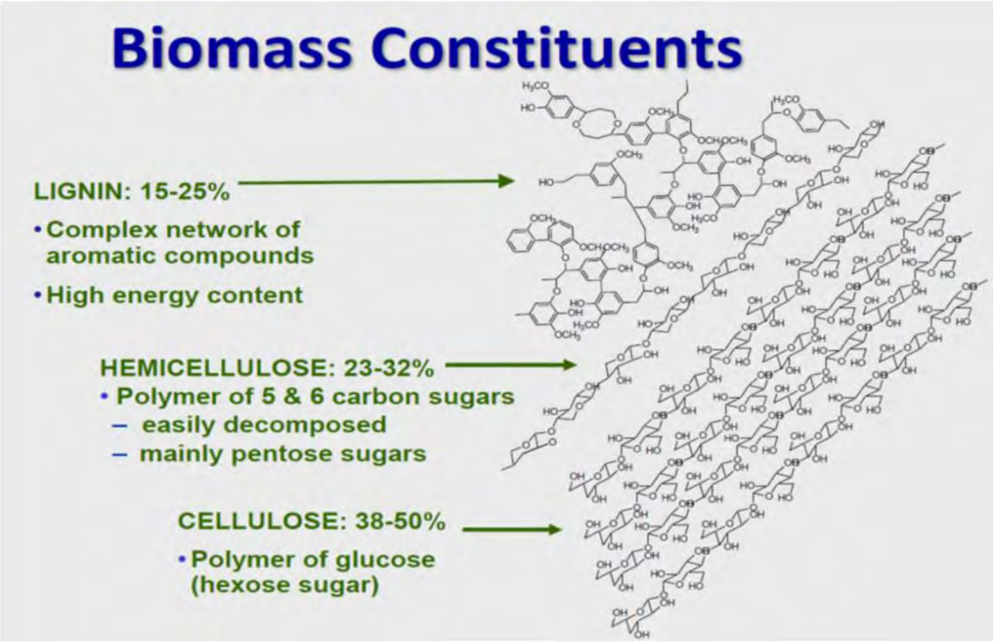
Roadmap for Biofuels

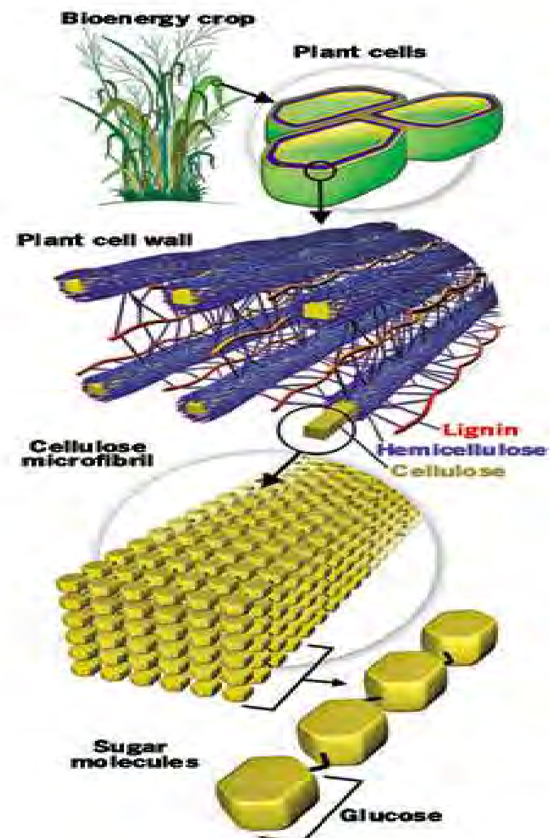


Lignocellulosic Biomass Components

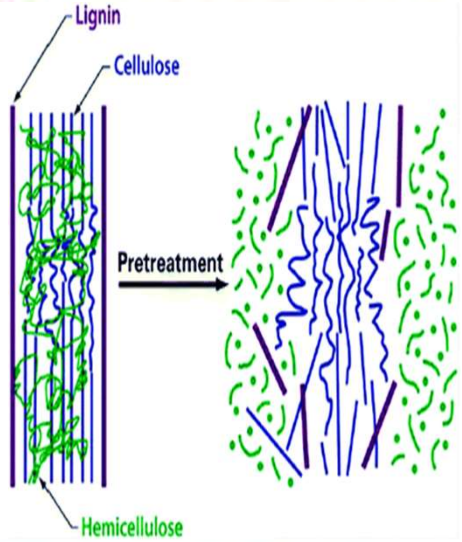
- *cellulose, hemicelluloses, and lignin make up dry matter of biomass > 90%*
- Small amounts of extraneous organic compounds (1- 4%) and about 6% others

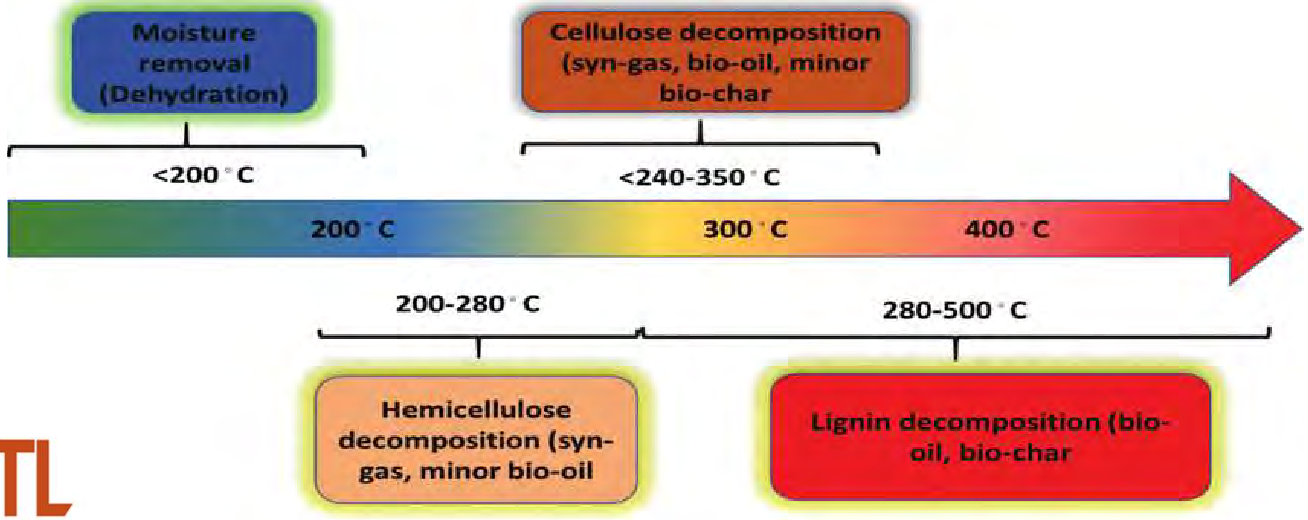


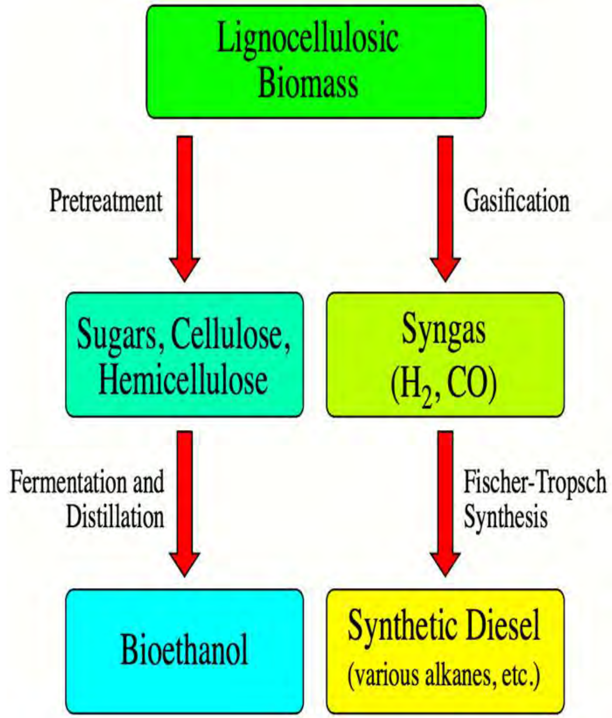




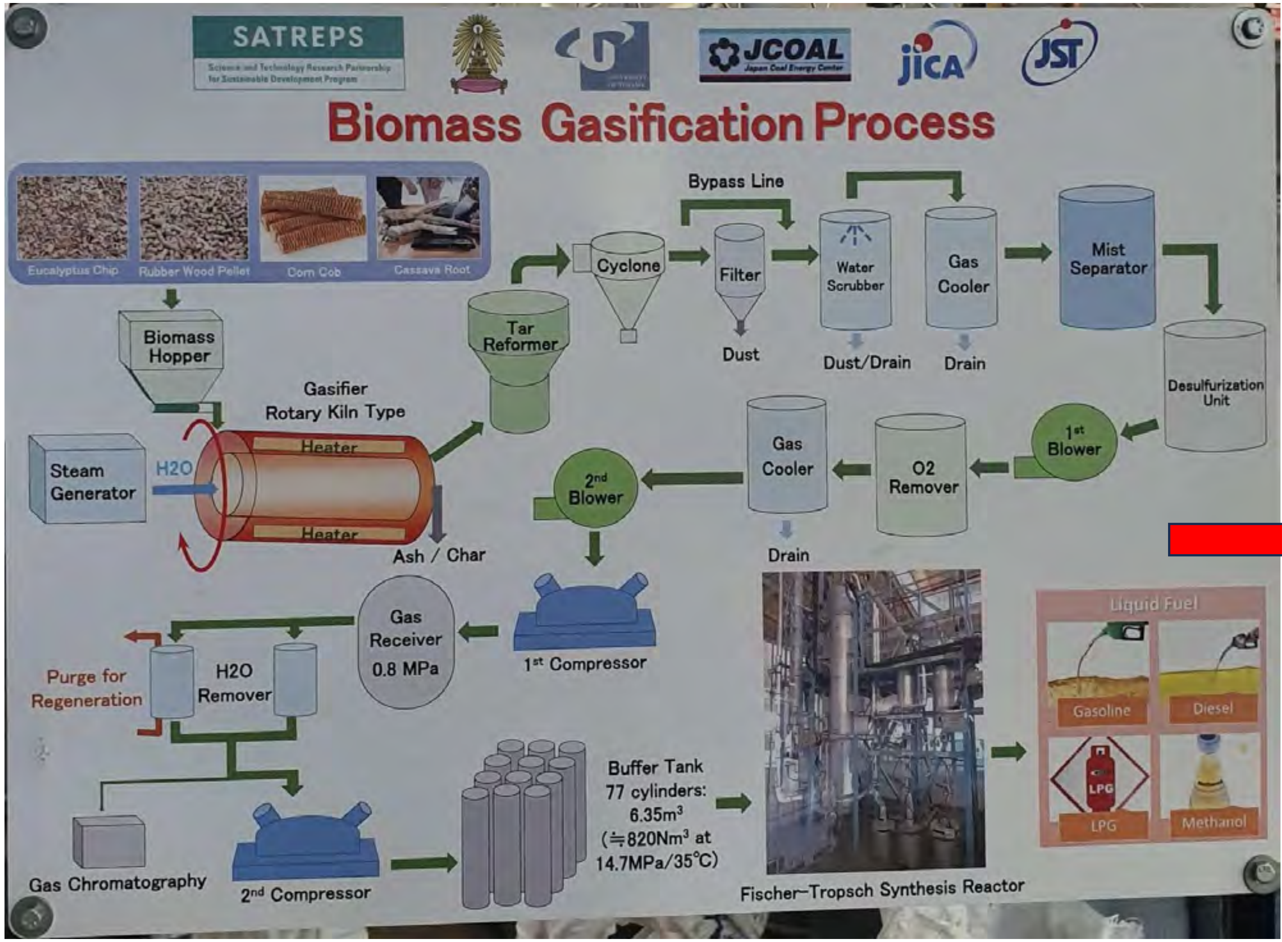
http://pubs.acs.org/cen/coverstory/86/8633cover3.html

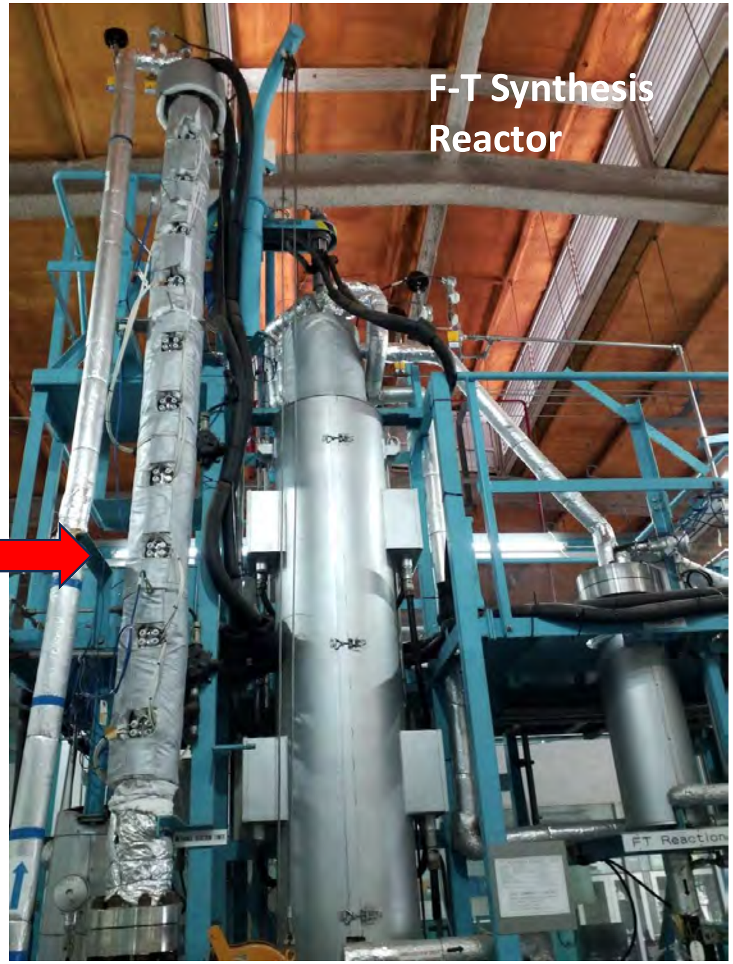

Lignin
Cellulose
Pretreatment
Hemicellulose


Moisture removal (Dehydration)
Cellulose decomposition (syn-gas, bio-oil, minor bio-char
<200 ° C
<240-350 ° C
200 ° C
300 ° C
400 ° C
200-280 ° C
280-500 ° C
Hemicellulose decomposition (syn-gas, minor bio-oil
Lignin decomposition (bio-oil, bio-char


Lignocellulosic Biomass
Pretreatment
Gasification
Sugars, Cellulose, Hemicellulose
Syngas (H_2, CO)
Fermentation and Distillation
Fischer-Tropsch Synthesis
Bioethanol
Synthetic Diesel
(various alkanes, etc.)

Modern Gasification Process





Advanced Combustion or Low Temperature Combustion Engine

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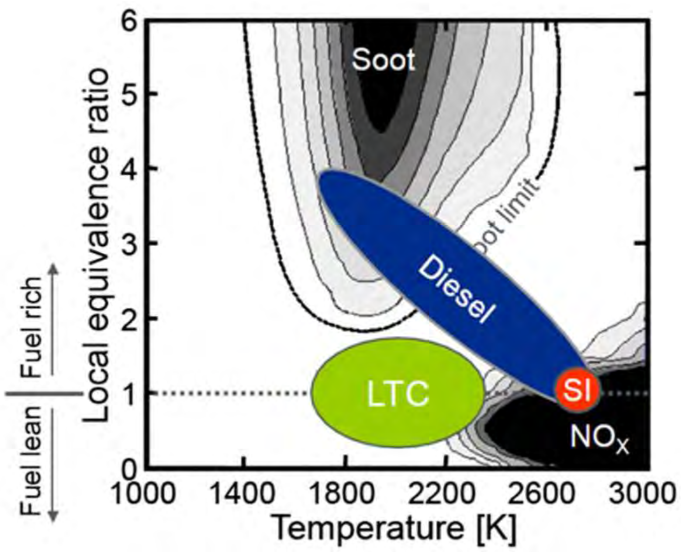
Background of Diesel Engine

- Direct injection diesel engines are used extensively as the prime movers for public transportation, agricultural and heavy machinery, and electricity generation because they enable high efficiency and lower fuel costs .
- However, diesel engine emissions are a significant contributor to environmental pollution, especially NOx and smoke.
- Emissions from diesel engines have become more important due to the increasing strictness of emission regulations.



Φ-T map

https://www.greencarcongress.com/2011/05/ltc1-20110520.html

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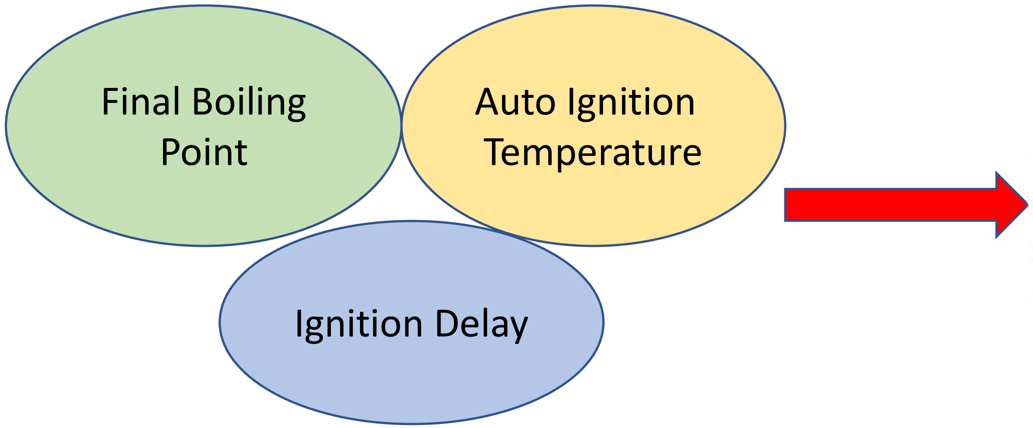
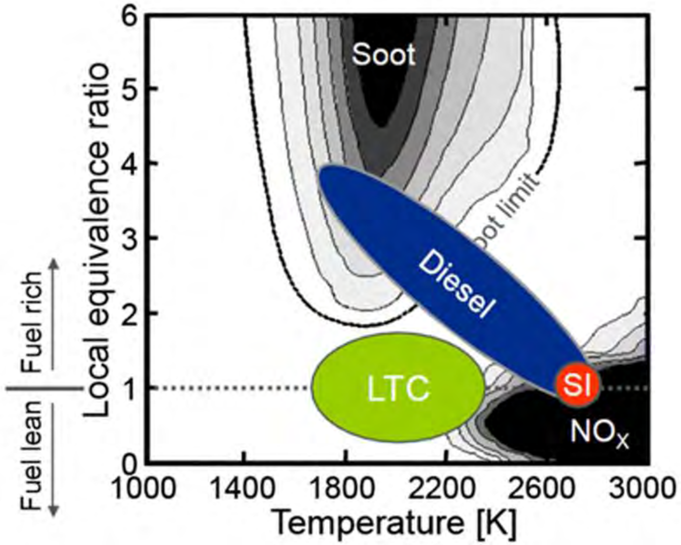
What is the Low Temperature Combustion?

- LTC in diesel engines is capable of avoiding NOx and PM formation zones.
- LTC is a general term for homogeneous charge compression ignition (HCCI), premixed charge compression ignition (PCCI), and reactivity control compression ignition (RCCI) combustion mode.

Premixed compression ignition (PCI) is a basic concept of LTC.





ii. Literature Review

Conventional Combustion

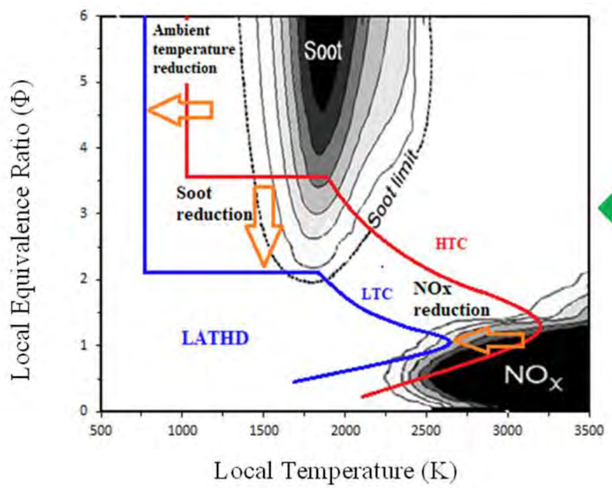
(Trade-off of NOx and Soot)

- Injection Timing
- Injection pressure

- Heavy EGR
- Low Compression Ratio
- Low Cetane Fuels

Low Temperature Diesel Combustion

(Trade-off of NOx and Soot & UHC and CO)

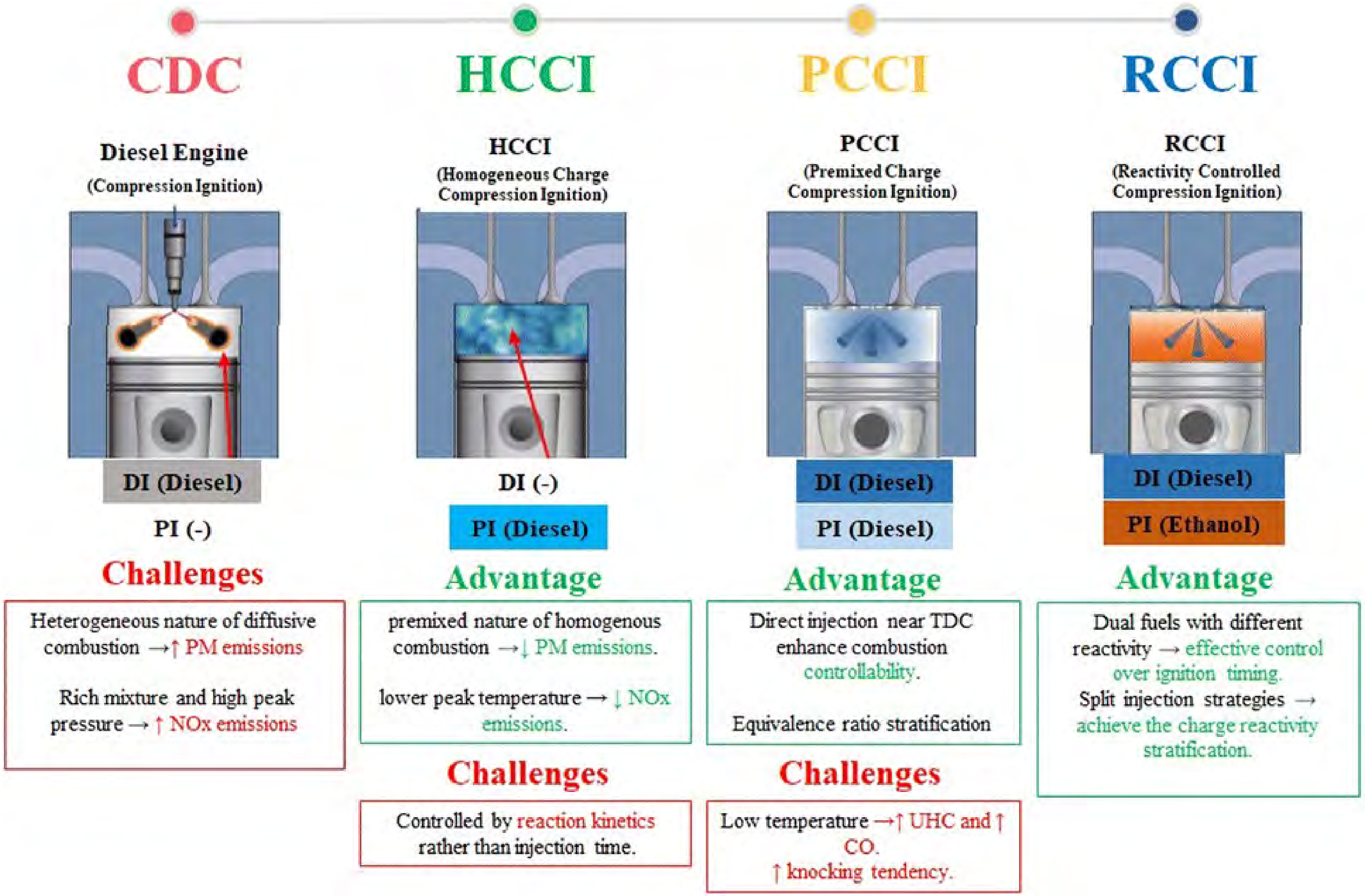


Low Ambient Temperature

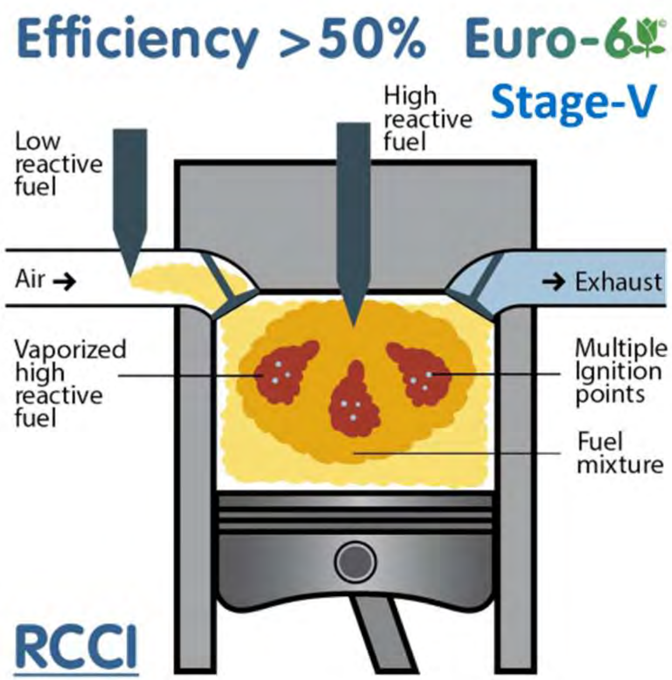
&

High Density

Advanced Combustion or Low Temperature Combustion Engine

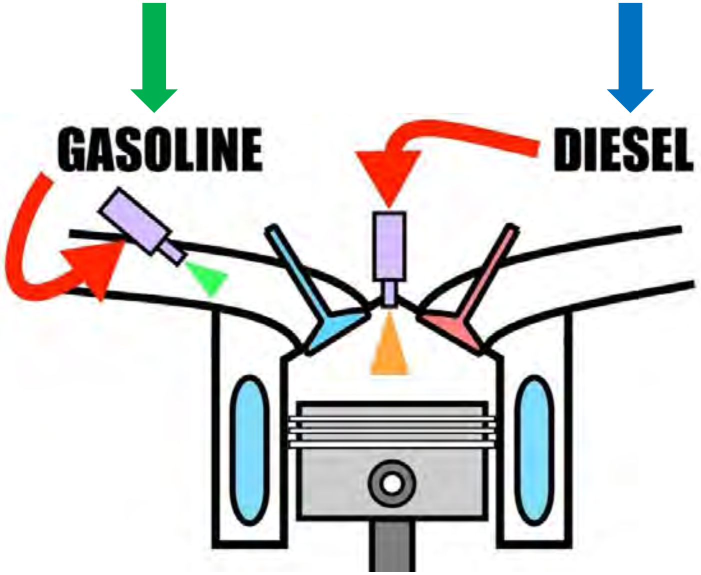


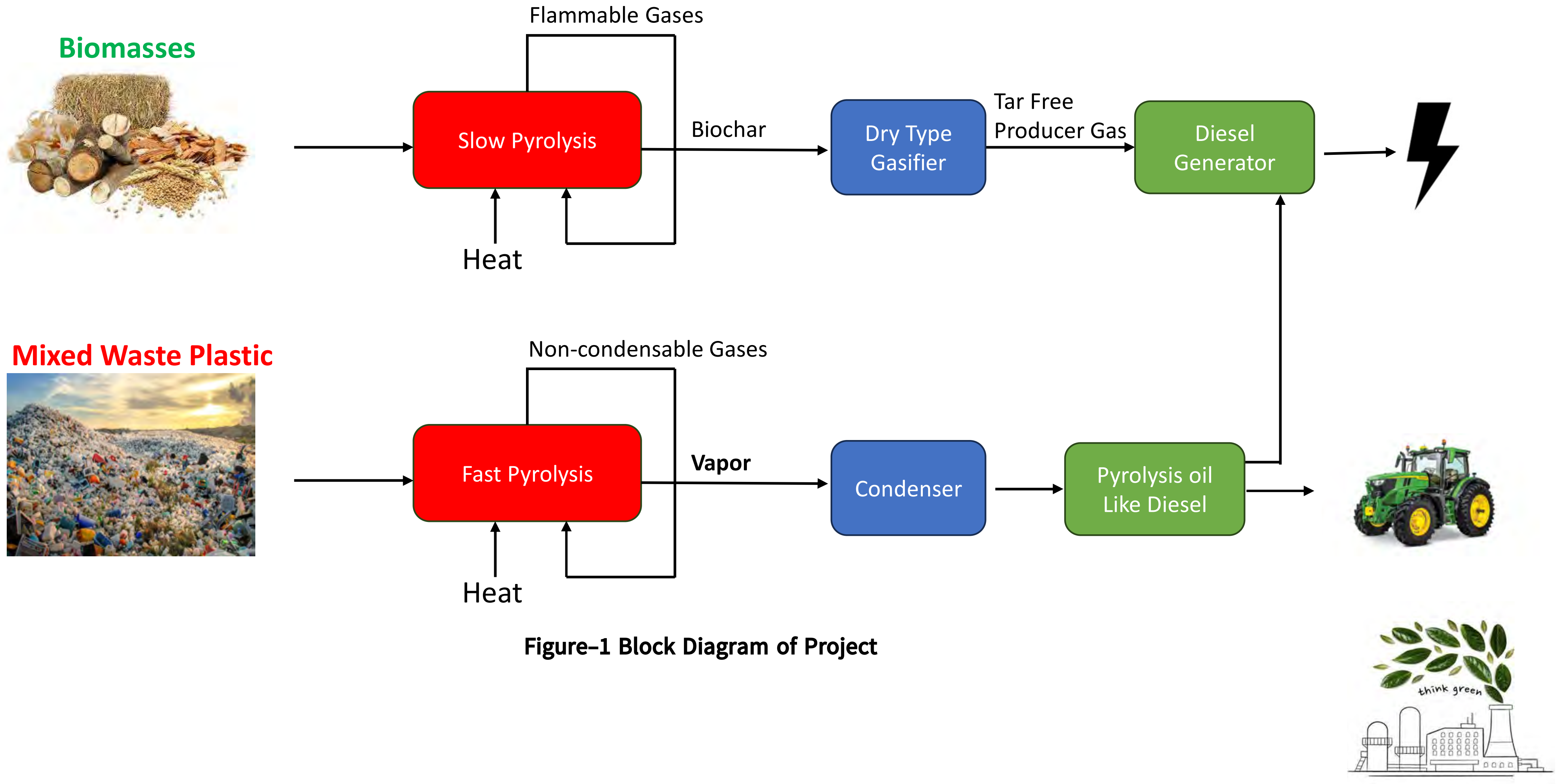
RCCI
Reactivity Controlled Compression Ignition



LRF such as gasoline, ethanol, biogas, **producer gas**

HRF such as diesel, biodiesel, **waste plastic oil**

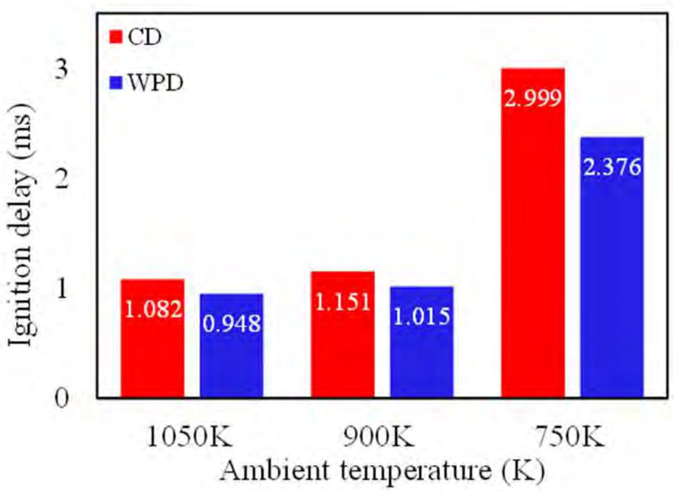


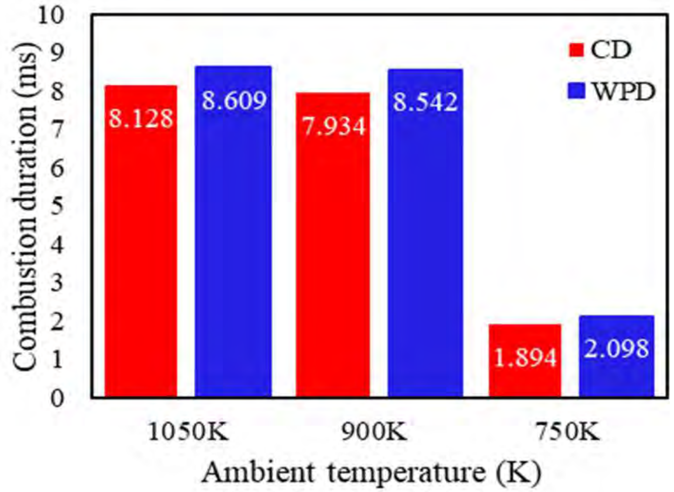


Figure–1 Block Diagram of Project

Results and Discussion

Ignition Delay and Combustion duration





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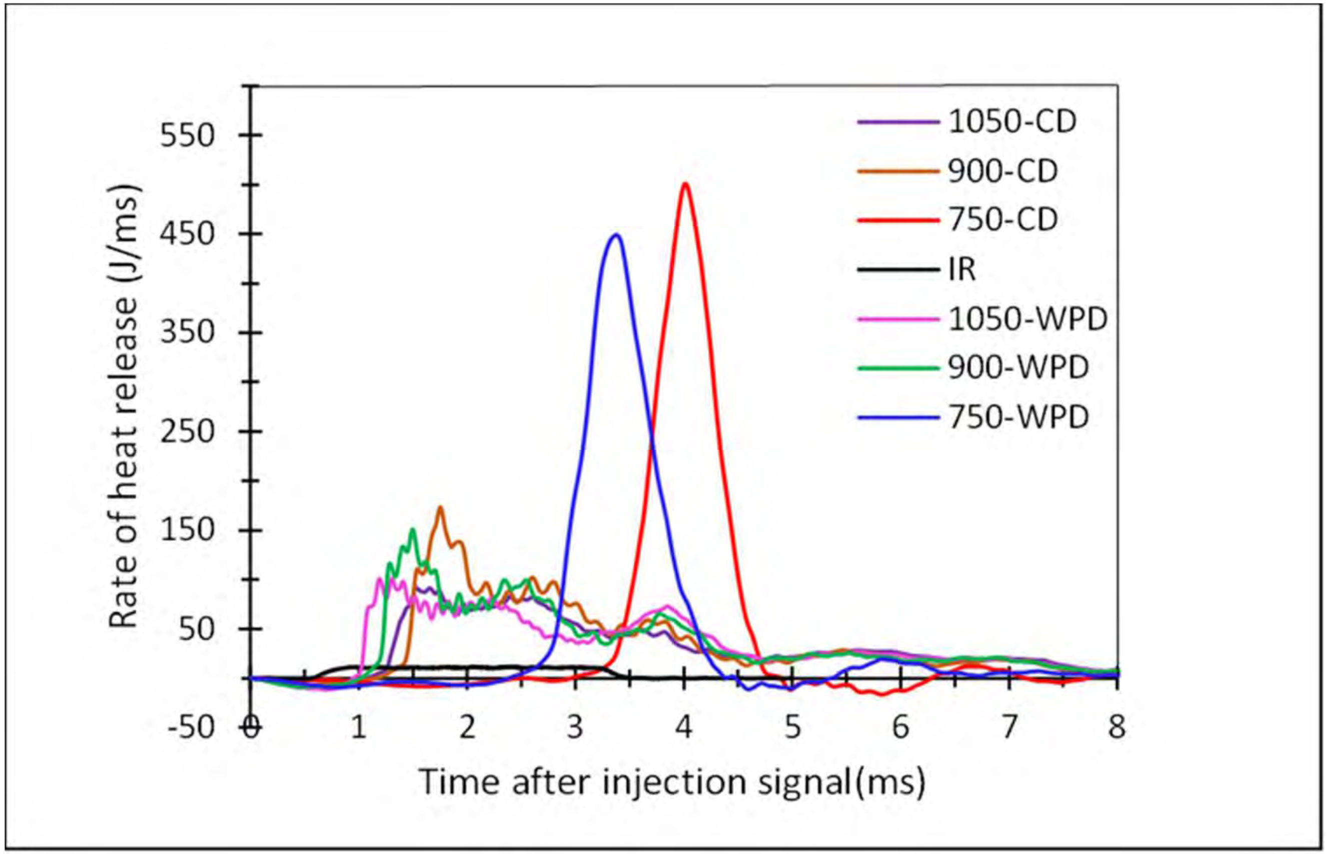
Heat Release Rate (HRR)



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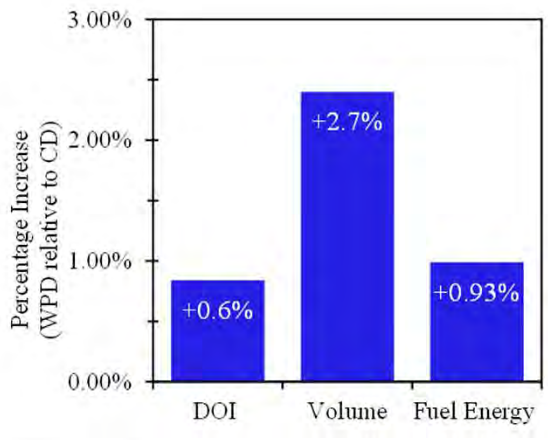
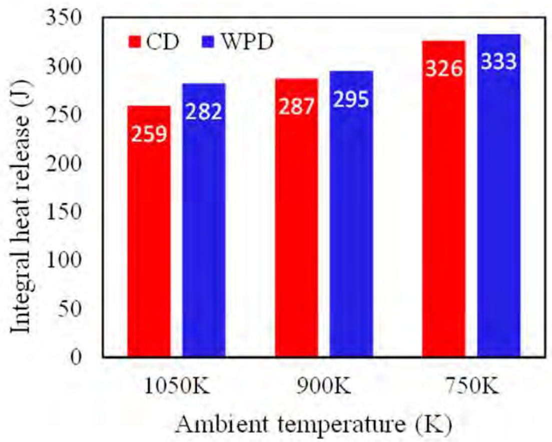
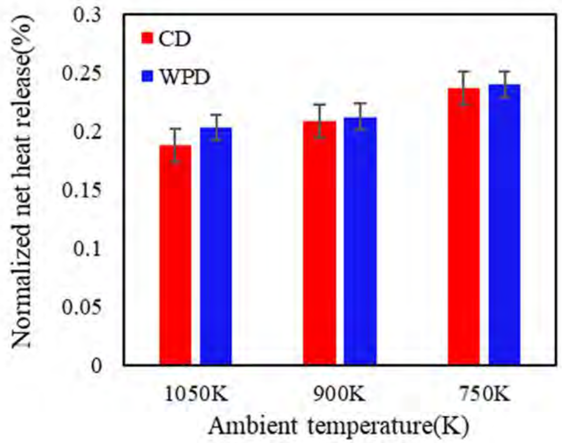
Integral Release Rate (IRR)

- **Heat transfer loss is greatly reduced with low flame temperature and a short combustion duration.**



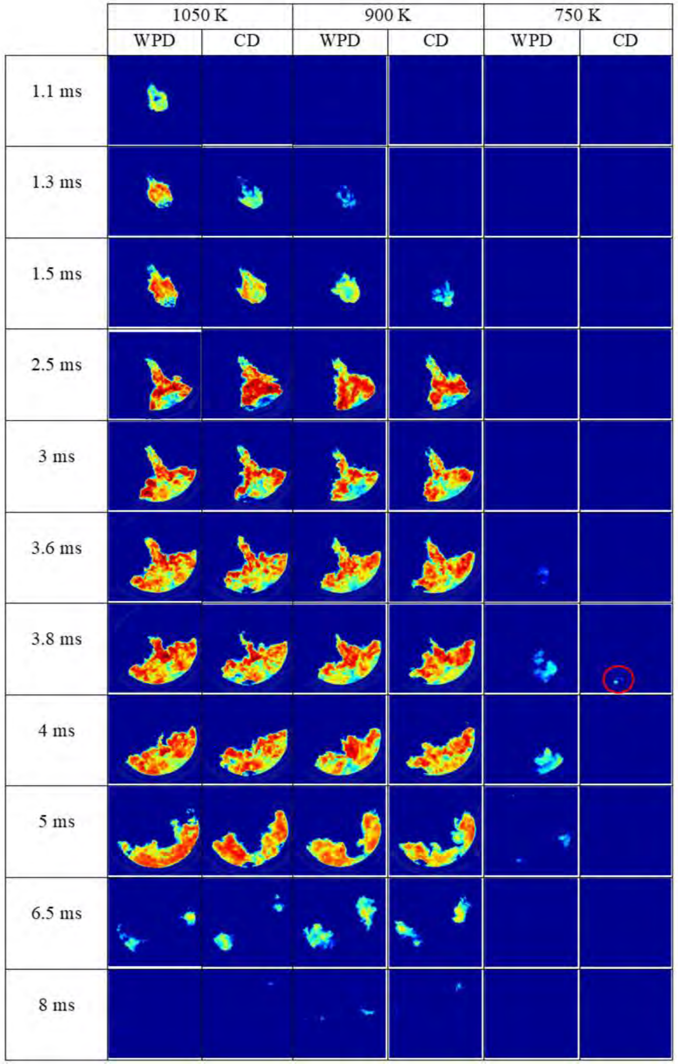




Spatial Distribution of Flame Temperature

$PV = mRT$

$Q = mc(T_2 - T_1)$



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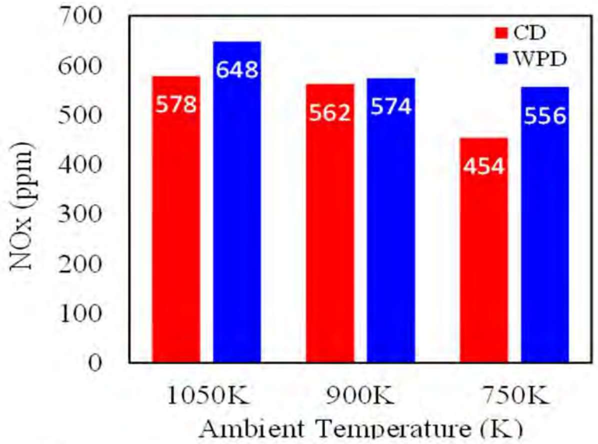
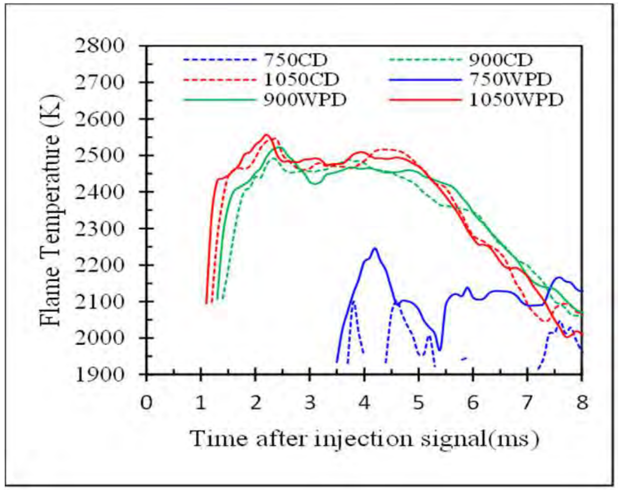
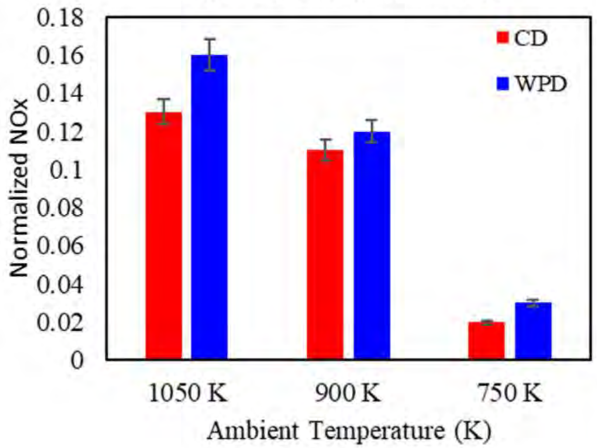
NOx Concentrations

- **The NOx of WPD was higher than that of CD because of higher flame temperature, even though it had a short ID and lower peak HRR.**
- **Therefore, IHR is a dominant factor to interpret NOx and flame temperature.**







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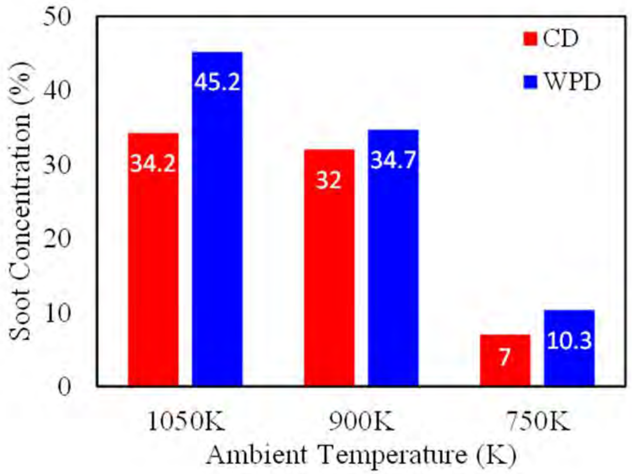
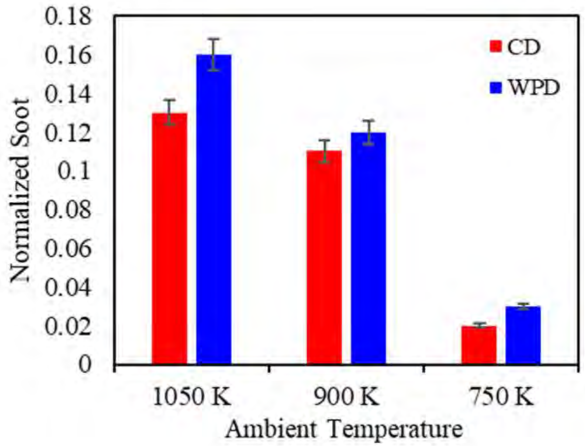
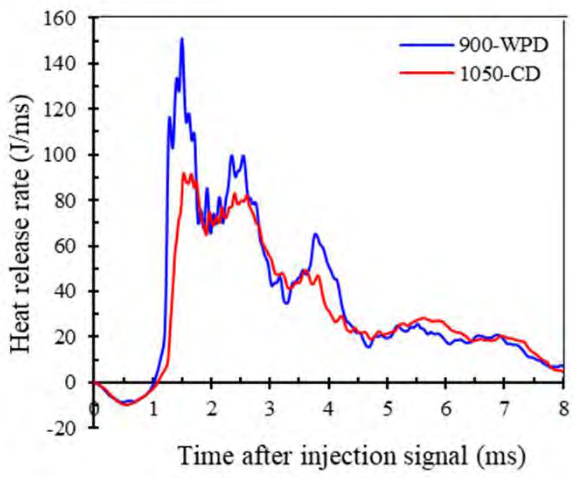
Soot Concentrations

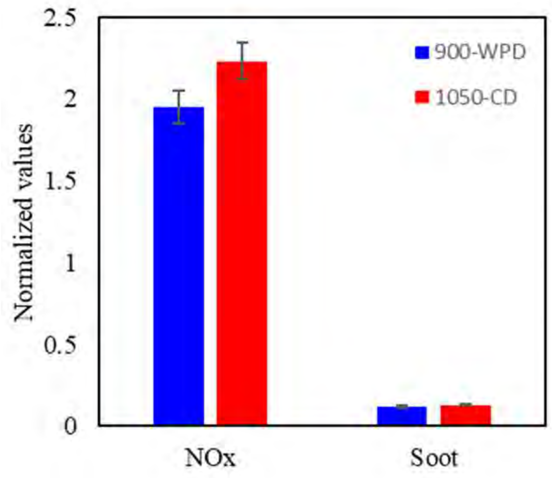
- The degree of homogeneity and lean mixture formation of CD can be increased more than WPD because of a longer ID.
- Therefore, soot concentrations of WPD are higher than that of CD.





NOx and soot concentrations at the same ignition delay





- **The soot formation tendency of low aromatic fuel is decreased at the same ID or cetane number.**
- **NOx formation is suppressed by the combined effect of low ambient temperature and high density.**
- **This information involves very important parameters for examining the optimum combustion phasing of different cetane fuels for real engine design.**

Potential of Waste Plastic Fuel for Myanmar

Outlines of Presentation

1. **Introduction**
   1. Background
   2. Literature Review
   3. Statements of Research
2. **Material and Methods**
3. **Results and Discussion**
4. **Conclusions and Recommendation**

Introduction

i. Background

- Plastics are essential materials due to their numerous applications in daily life. Consequently, a huge number of plastic products accumulate as waste in the environment.

- Plastic waste is a big issue in the world including Thailand, because the amount of recycled plastic remains low due to recycling problems.

https://investforesight.com/russia-to-ban-single-use-plastic-items/

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Continued

https://investforesight.com/russia-to-ban-single-use-plastic-items/

- One of the recycling problems is economy as they need to be collected separately or sorted before the process can begin. Most plastics are not compatible with each other and hence they cannot be processed together during recycling.

- For instance, a polyvinyl chloride (PVC) bottle in polyethylene terephthalate (PET) recycle can ruin the entire batch by becoming yellowish and brittle.

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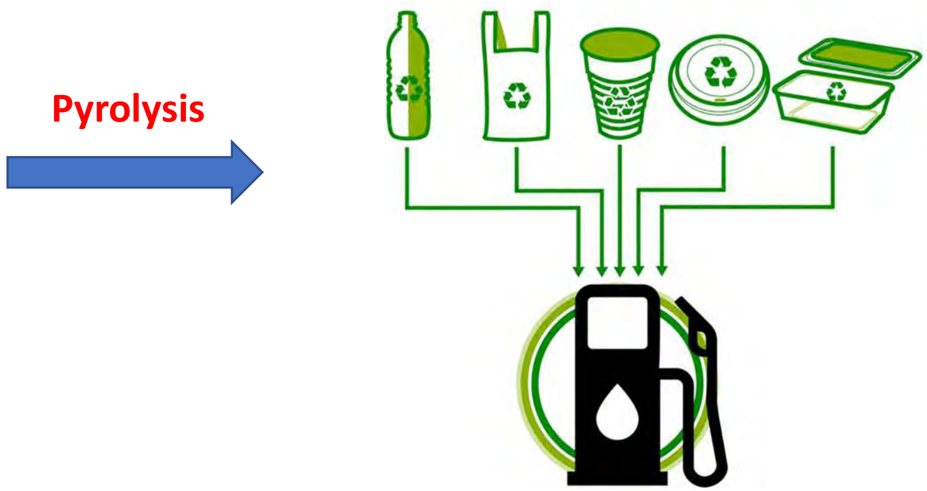
Continued

Unlike mechanical recycling, pyrolysis (chemical recycling) does not require a keen sorting of different plastics. Fast pyrolysis of waste plastic into valuable fuels is effective method in the waste disposal management and it can be used as alternative fuel for internal combustion engines.



https://theconversation.com/if-we-cant-recycle-it-why-not-turn-our-waste-plastic-into-fuel-96128
https://www.thechemicalengineer.com/news/neste-aims-to-turn-plastic-waste-into-fuel/

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ii. Literature Review

- In previous studies, Waste plastic fuels were produced from each type of waste plastic. After that, identify the chemical compounds using GC-MS and GC-FID, investigate on physical properties and testing engine performance.
- Thailand produces around 3.5 million tonnes of plastic trash, only 18% of which is recyclable, according to the market analysis for Thailand: plastics circularity potential and hurdles.
- 2.88 million tonnes of plastics are disposed of (i.e., not recycled) each year, and 87% of the material value (USD 3.6-4 billion/year) of plastics is lost.

https://investforesight.com/russia-to-ban-single-use-plastic-items/

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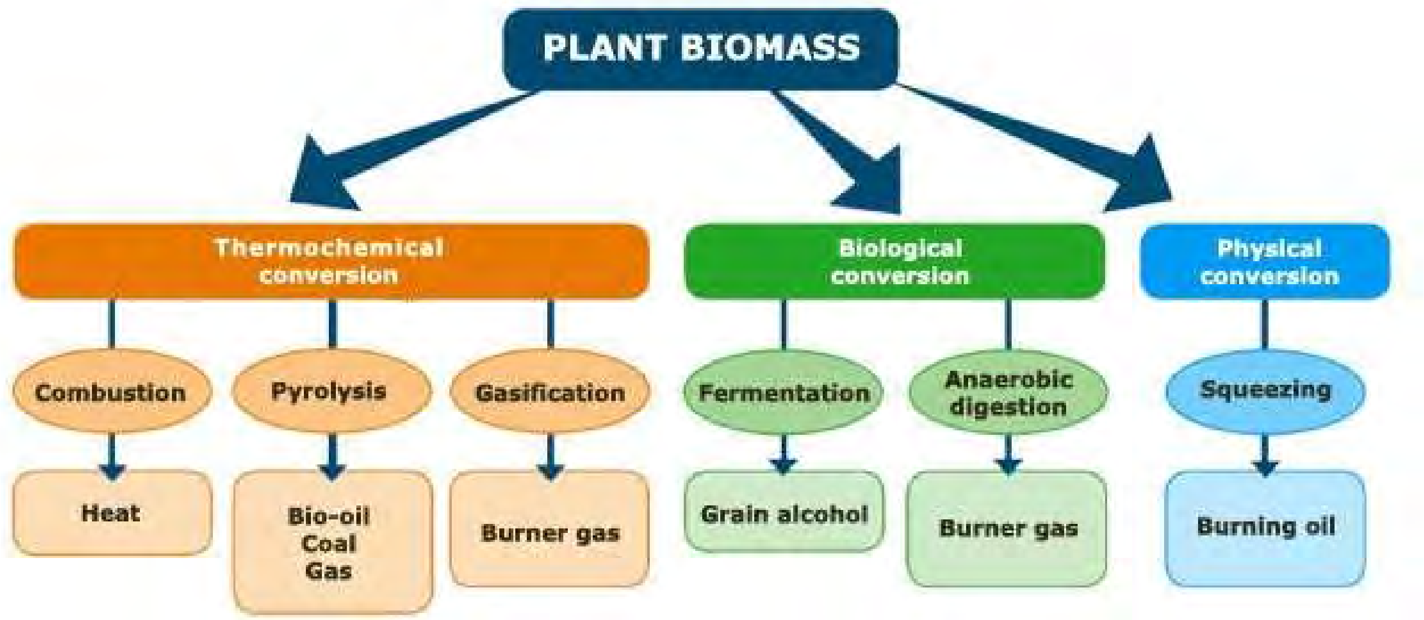
iii. Statements of Research

- **Research Gap**-In previous research, there were no studies about the characterization of alternative diesel that was produced commercially from real mixed waste plastic.

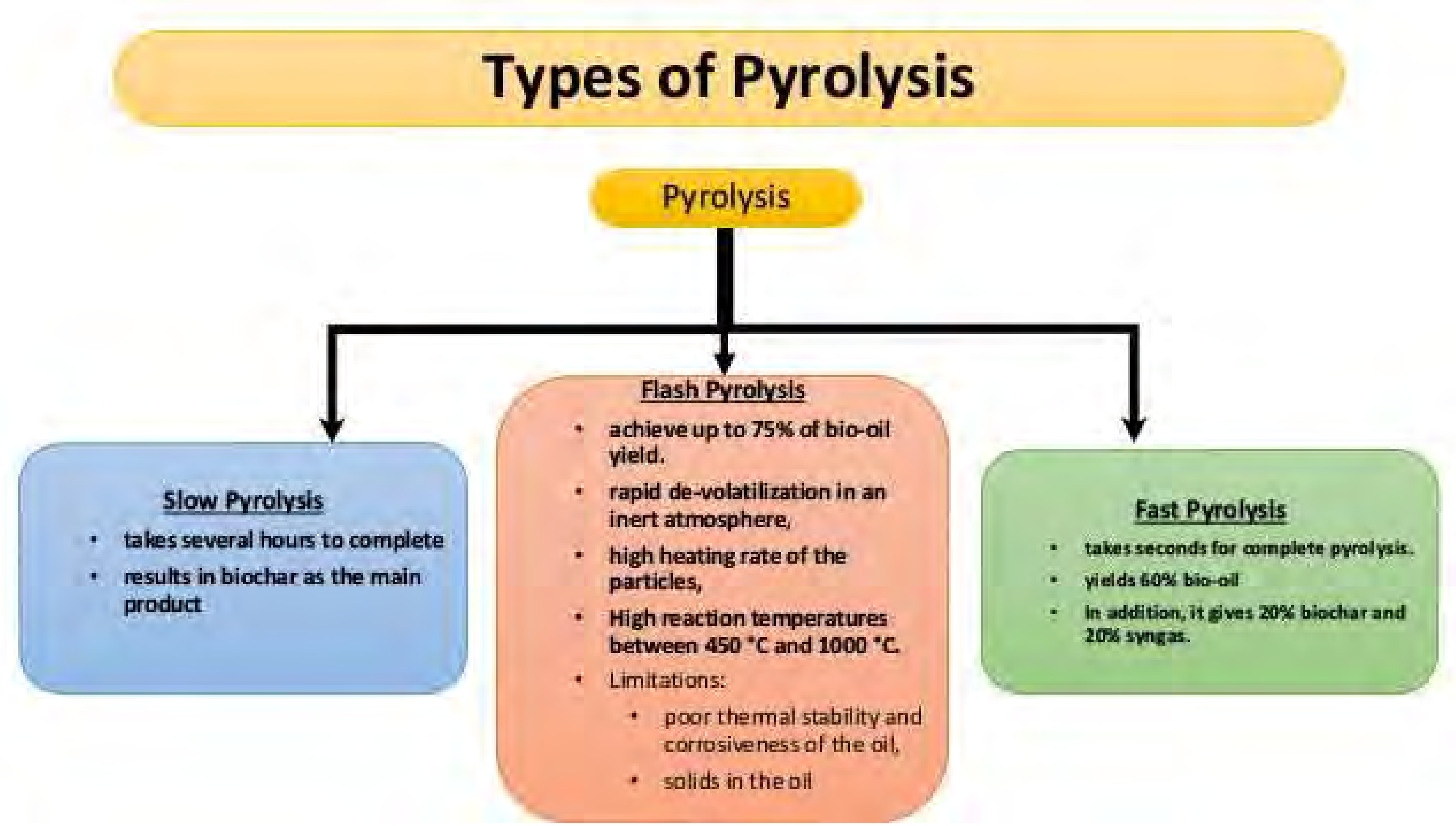
- **Objective**-The purpose of the research is to study the fuel characteristics of waste plastic diesel and compare them to commercial diesel in order to determine whether the fuel quality could possibly be used in current diesel engines and the appropriate method for fuel upgrading.

- **Contribution**- Propose to investigate fuel cleanliness, physical properties, CHS contents, Carbon number contents, distillation curve, and PNA contents of waste plastic diesel and commercial diesel. Studying the relationship of fuel properties is fuel characterization.

Biomass Conversion Process



https://theconversation.com/if-we-cant-recycle-it-why-not-turn-our-waste-plastic-into-fuel-96128
https://www.thechemicalengineer.com/news/neste-aims-to-turn-plastic-waste-into-fuel/



https://theconversation.com/if-we-cant-recycle-it-why-not-turn-our-waste-plastic-into-fuel-96128
https://www.thechemicalengineer.com/news/neste-aims-to-turn-plastic-waste-into-fuel/

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Pyrolysis – thermal decomposition of carbonaceous material in the absence of oxygen.

Figure: Schematic diagram of pyrolysis process

https://www.bioenergyconsult.com/wp-content/uploads/2012/02/Pyrolysis.jpg

2.Materials and Methods

2.1. Materials

- The waste plastic diesel utilized in this study were derived from catalytic fast pyrolysis of real mixed waste plastic (HDPE, PVC, LDPE, PE,PP,PS) and commercial diesel (B7) of Thailand.

Pyrolysis – Thermal decomposition of carbonaceous material in the absence of oxygen.

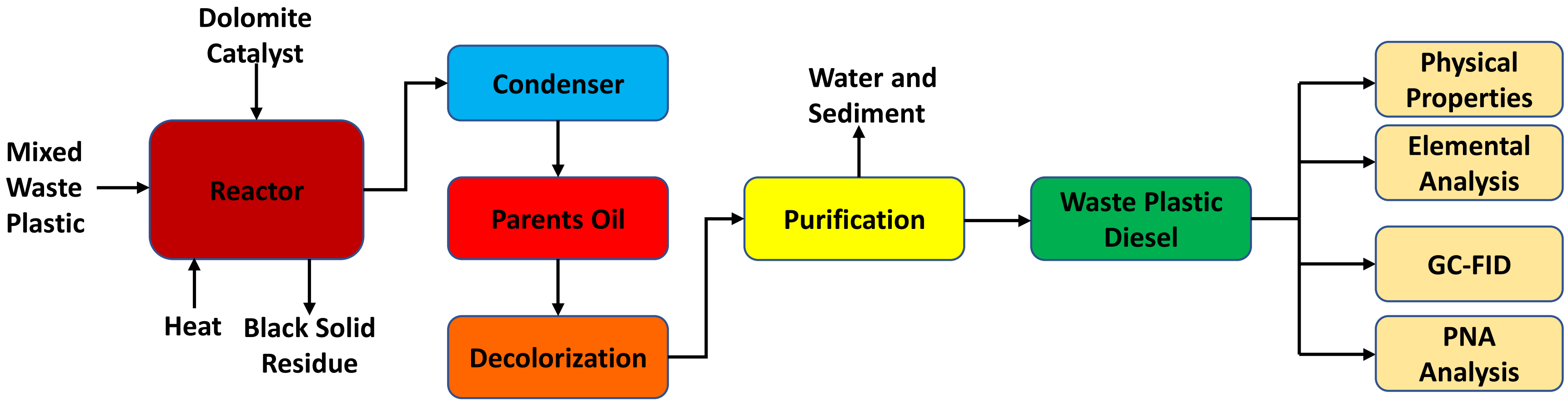
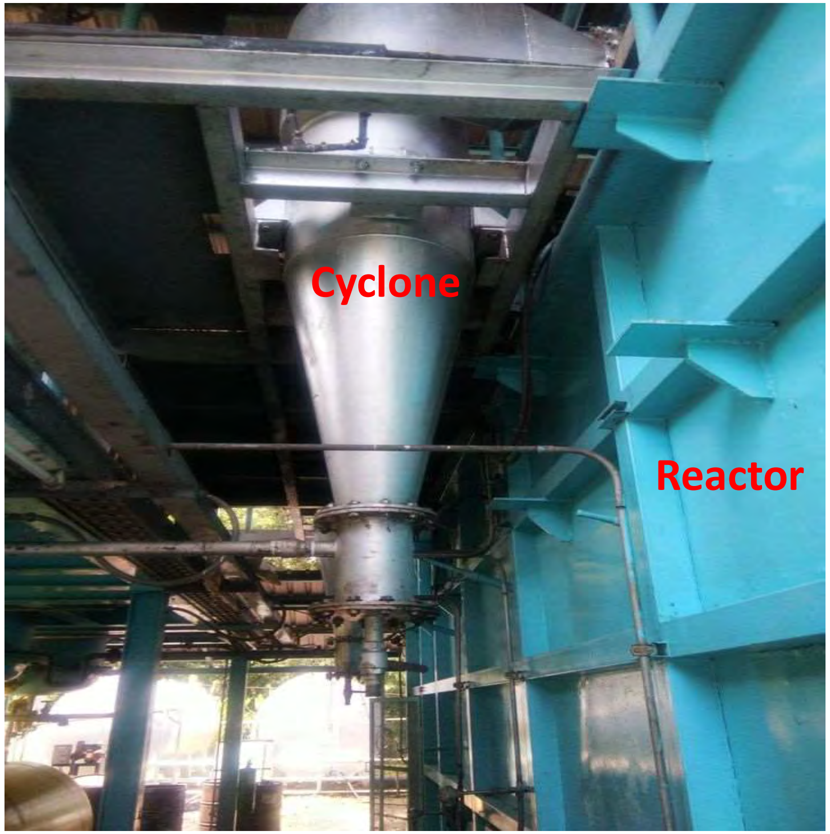


Fig. Waste plastic diesel production process and its characterization methods

Continued



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2.1 API Method (PNA Composition Analysis)

$$v = 2.51(n - 1.475) - (d - 0.851) \quad \text{(Eq.1)}$$

$$a = 430 \; if \; v > 0 \; and \; 670 \; if \; v < 0$$

$$\%C_A = av + 3660/M \quad \text{(Eq.2)}$$

$$w = (d - 0.851) - 1.11(n - 1.475) \quad \text{(Eq.3)}$$

$$\%C_R = 1440w - 3\%S + \frac{10600}{M} \; if \; w < 0 \quad \text{(Eq.4)}$$

$$\%C_R = \%C_N + \%C_A \quad \text{(Eq.5)}$$

$$\%C_P = 100 - \%C_R \quad \text{(Eq.6)}$$

- The method is included in the ASTM manual under ASTM D3238.
- It calculates the distribution of carbon in paraffins(%C_p), naphthenes(%C_N), and aromatics(%C_A) using equation 1 to 5.
- The refractive index and density at 20°C and molecular weight are used as input data, which are estimated from correlations that are adopted in API-TDB.

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2.2 Physical Properties and Elemental Analysis

1). Physical Properties

The ASTM procedures were utilized to test the minimum laboratory data as well as another needed feature that may assess fuel quality so that it can be used in current engines without issue.

2). Elemental Analysis

The carbon, hydrogen, and sulfur contents were determined using ASTM D5373 and D5453.

2.3. Simulated Distillation Method

- Simulated distillation is a Gas Chromatographic technique for determining the boiling point distribution of fuels by Flame Ionization Detection (GC-FID).
- Two standard solutions were used for quantification of waste plastic diesel and commercial diesel: normal alkanes ranging n-C_5 to n-C_{10} and n-C_{10} to n-C_{40}.

Table. Experimental condition for ASTM D2887

Column	DB-10,10mx0.53mm,2.65µm
Column temperature	40°C to 350°C
Carrier gas flow rate	13.989 L/min (helium)
Injection temperature	350°C
FID temperature	375°C
Gas flow rate	
Nitrogen (makeup)	45 mL/min
Hydrogen	40 mL/min
Air flow	450 mL/min
Injection volume	0.1 µL

3.Results and Discussion

3.1 PNA Composition Analysis

TABLE. PNA CONCENTRATION OF FUELS

Hydrocarbon Type	CD	WPD
Paraffins (%)	72	77
Naphthene (%)	22	20
Aromatics (%)	6	3

- Paraffin and aromatic ratio of WPD is higher than that CD.

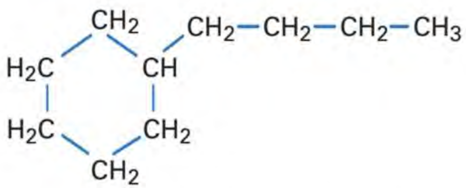
Figure: Commercial Diesel (left) and Waste plastic diesel (right)

n-Paraffin

$CH_3-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_3$

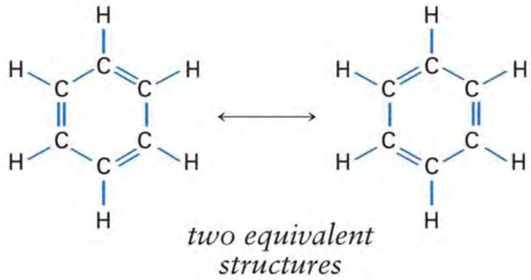
n-Decane $C_{10}H_{22}$

Naphthenes



Butylcyclohexane $C_{10}H_{20}$

Aromatic Compounds



Benzene C_6H_6

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3.2 Physical Properties and Elemental Analysis

TABLE. PHYSICAL PROPERTIES AND CHS CONTENTS OF TEST FUELS

Property	ASTM Method	CD	WPD
API gravity	D1250	37.2	44.2
Density@15°C (kg/m³)	D4052	837	806
Viscosity@40°C (Cst)	D445	3.28	3.17
Viscosity@100°C (Cst)	D445	1.28	1.34
Viscosity Index	D2270	103.4	274.6
T_{10} (°C)	D86	208	182
T_{50} (°C)	D86	288	291
T_{90} (°C)	D86	352	385
Cetane Index	D976	56.43	67.93
Energy Content (MJ/kg)	D240	45.86	46.29
Flash Point (°C)	D93	69	38
Auto ignition Temp (°C)	E-659	218	201
Sulfur Content (wt. %)	D5453	0.003	0.014
Carbon Content (wt. %)	D5373	84.75	83.45
Hydrogen Content (wt. %)	D5373	13.62	14.14
H/C Atomic Ratio		1.93	2.03
Fatty acid methyl ester	EN14078	8.7	0

- The API gravity can be used to determine the hydrocarbon type and fuel quality. Energy content of fuels is proportional to their API gravity.
- Aromatic hydrocarbons have lower API gravity than paraffinic hydrocarbons.
- High VI value indicates little fluctuation in viscosity with temperature, which is characteristic of paraffinic oils.
- Greater cetane index has a lower specific gravity and a higher T50.

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3.3 Simulated Distillation Method

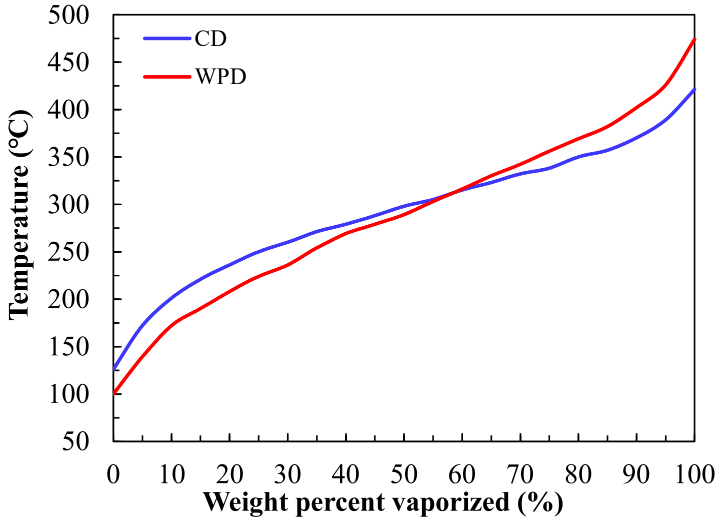

Fig. Comparison distillation curves of CD and WPD

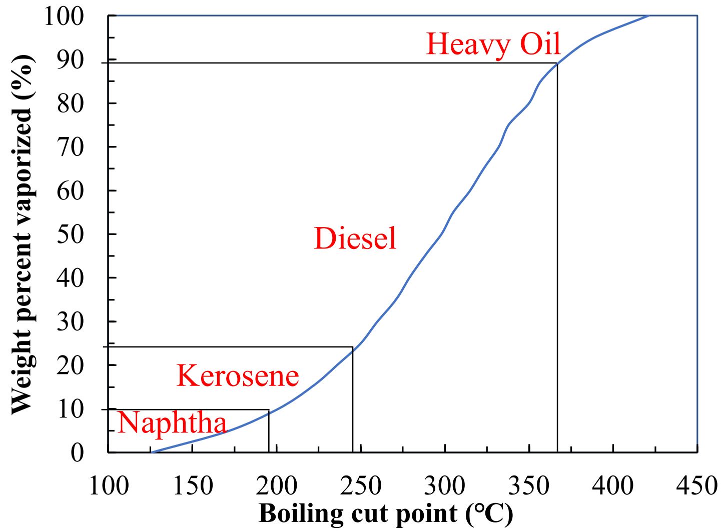

Fig. Distillation curve with cut points

- The initial boiling range of WPD is over 60% lower while the end boiling range is nearly 40% greater than that of CD. Because it contains lighter and heavier compounds than CD, WPD is also known as wide distillation fuel (WDF).

Composition	Cut point range	CD wt.%	WPD wt.%
Naphtha	IBP-200°C	9.6	18.8
Kerosene	200-250°C	15.4	14.7
Diesel	250-370°C	65.2	47.8
Heavy Oil	370-FBP	9.8	18.7

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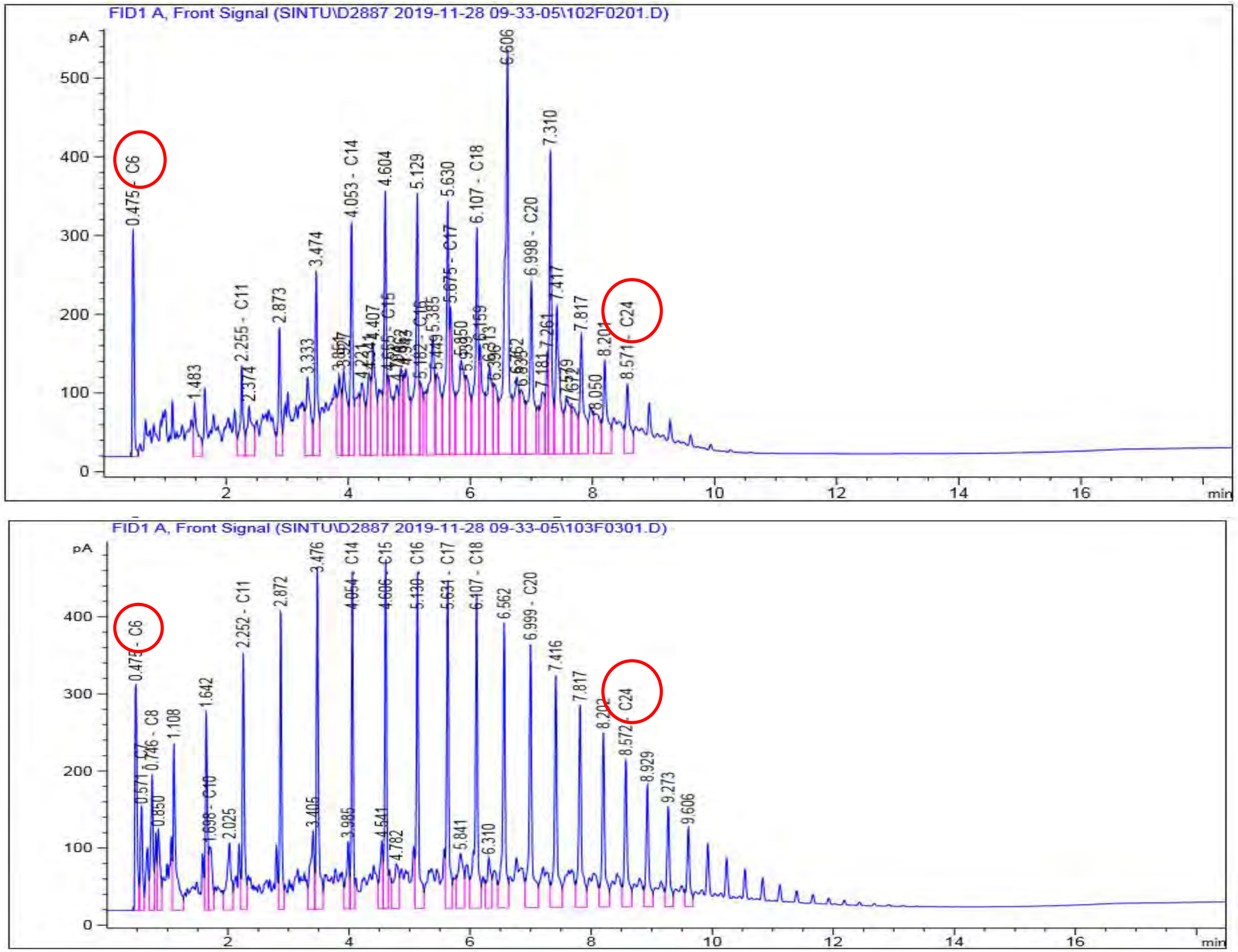

Figure. Chromatogram of CD(above) and WPD(below)

Table. Constituents(area%) identified by GC-FID

Carbon Content	CD	WPD
C_5	Not detected	Not detected
C_6	2.1457	3.38784
C_7	Not detected	1.71151
C_8	Not detected	2.35746
C_{10}	Not detected	1.41769
C_{11}	1.38791	3.71853
C_{14}	2.84199	4.32735
C_{15}	1.72030	4.77871
C_{16}	1.07963	5.20978
C_{17}	2.42153	5.19759
C_{18}	3.68398	6.00175
C_{20}	3.59628	5.52902
C_{24}	1.47851	3.10487
-	Not detected	2.52215
-	Not detected	2.06772
-	Not detected	1.61383
C_{28}	Not detected	Not detected
C_{32}	Not detected	Not detected
C_{36}	Not detected	Not detected
C_{40}	Not detected	Not detected

- The primary carbon number distributions in CD are C_{11} to C_{24} since C_7 to C_{10} are not present.
- WPD has three peaks between C_{24} and C_{28}, which might be C_{25} to C_{27}, and its carbon number distributions range from C_6 to C_{24}.
- For both fuels, the C_5 and C_{28}-C_{40} are not found.

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Fuel Cleanliness and Compatibility with Existing Hardware

Property	ASTM Method	CD	WPD
Ash Content (wt. %)	D482	0.001	0.001
Copper strip corrosion	D130	1a	1a
Total Acid Number (mgKOH/g)	D664	0.27	0.26
Water Content (wt.%)	D6304	0.45	0.29
Carbon Residue %		0	0
Asphaltene content %		0	0
Particle Count	D7619	17/14/10	18/16/13

- Water content, copper strip corrosion, total acid number which are degree of corrosivity of fuel.
- Ash, asphaltene contents and carbon residue (%CR) are important to access deposition potential in engine.
- Particle content represent impurity of fuel.
- Ash come from oil or water-soluble metallic compounds.
- If the fuel's H/C ratio is larger than 1.71, %CR from fuel combustion can be precisely predicted to be zero. Lower CR values signify better fuel quality and higher hydrogen.
- The amount of n-pentane in a fuel could be used to assess its asphaltene concentration.

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7 THB per Liter

Parameters	Test Method	CD	WPD
Water and Sediment %vol (Before filter)	ASTM D2709	<0.01	10 (max 0.05)
Water and Sediment %vol (After filter)	ASTM D2709		0.03
Particle Count (Before filter)	ASTM D7619	17/14/10	21/19/13(max 18/16/13)
Particle Count (After filter)	ASTM D7619	17/14/10	18/16/13
Water Content Wt.% (Before filter)	ASTM D6304	0.045(max0.03)	0.097
Water Content Wt.% (After filter)	ASTM D6304		0.027

4. Conclusions and Recommendation

- According to ASTM standards and API-TDB correlations, WPD has greater material compatibility, corrosivity, and depositions than CD. As a result, WPD could possibly be used in current engines without modification or issue.
- WPD, on the other hand, must be blended with CD since its sulfur content fails to meet Euro 4 standard.
- The demand for diesel in Thailand was 26.94 billion liters per year in 2021. According to rough calculations, 2.33 billion liters of WPD can be produced from 2.88 million metric tons of unrecycled plastics with a 65% conversion efficiency.
- As it is only 8.65% of diesel demand, it can be blended with CD in order to decrease sulfur concentration without significant changes in bulk properties. If not, it can be used in non-road engines such as farm machinery, construction equipment, generators, and boats.
- If the production cost of WPD is the same as the market price of CD, about USD 2.1 billion may be returned to Thailand's financial system. It is, in fact, less expensive.
- Alternative fuel production from waste plastic pyrolysis is an efficient waste management technology.

7 THB per Liter

Acknowledgement

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References

1. W Khatha., S Ekarong., M Somkiat., S Jiraphon.,2020. Fuel properties, performance and emission of alternative fuel from pyrolysis of waste plastics. IOP Conf. Series: Materials Science and Engineering 717.
2. Fazal Mabood., M.R.Jan Jasmin Shah., Farah Jabeen., 2012. Catalytic pyrolysis of waste plastic and tyres. LAP LAMBERT academic publishing, U.S.A.
3. Anandhu, V., Jilse, S., 2018. Pyrolysis process to produce fuel from different types of plastic- a review. IOP Conf. Series: Materials Science and Engineering 396.
4. Brajendra, K.S., Bryan, R.M., Karl, E.V., Kenneth, M.D., Nandakishore, R., 2014. Production, characterization and fuel properties of alternative diesel fuel from pyrolysis of waste plastic grocery bags. Fuel processing technology 122, 79-90.
4. A.M. Motawie., Hala. B.I., Hasabo, M.A., Sahar, M.A., R.M, Abualsoud., 2016. Fractional distillation of fuel from mixed plastic waste. Conference paper.
5. Z.T, Aung., C, Charoenphonphanich., H, Kosaka., P, Ewphum., P, Srichai., 019. Investigation on physical properties and measurement of bulk modulus of waste plastic diesel. The 10th AUN/SEED-NET RCMEManuE,129-132.
6. M.R, Riazi., 2005. Characterization and properties of petroleum fractions. 1st ed. ASTM, U.S.A.
7. J, Wang., Z, Wang., H, Liu., 2015. Combustion and emission characteristics of direct injection compression ignition engine fueled with full distillation fuel. Journal of fuel 140, 561-567.
8. https://www.bangkokpost.com/business/2495941/countrys-fuel-usage-up-13-5-in-2022
9. https://www.statista.com/statistics/1304915/thailand-production-volume-of-diesel/

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