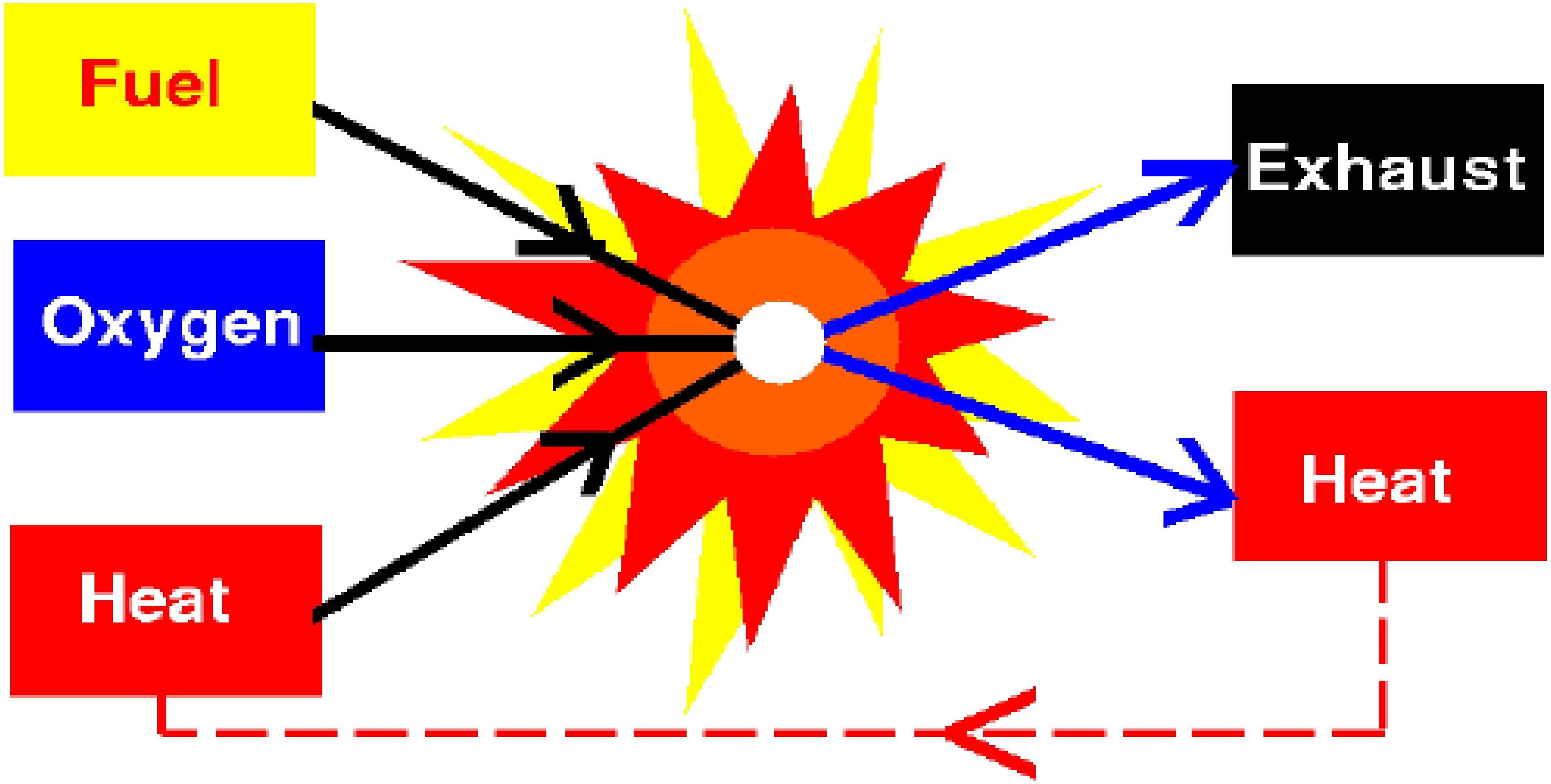
FUELS

Introduction

- Why do we study about Fuel for IC Engine?
  - Because fuel properties affect the combustion process in engine and its operation
  - Engines are designed to run on fuels that meet certain standards in terms of chemical and physical properties
  - Quality of fuel can affect engine durability
  - To understand the attendant ill-effect of fuels that used for IC engine on environment and human health
  - Depletion of petroleum based fuel for IC Engine from time to time

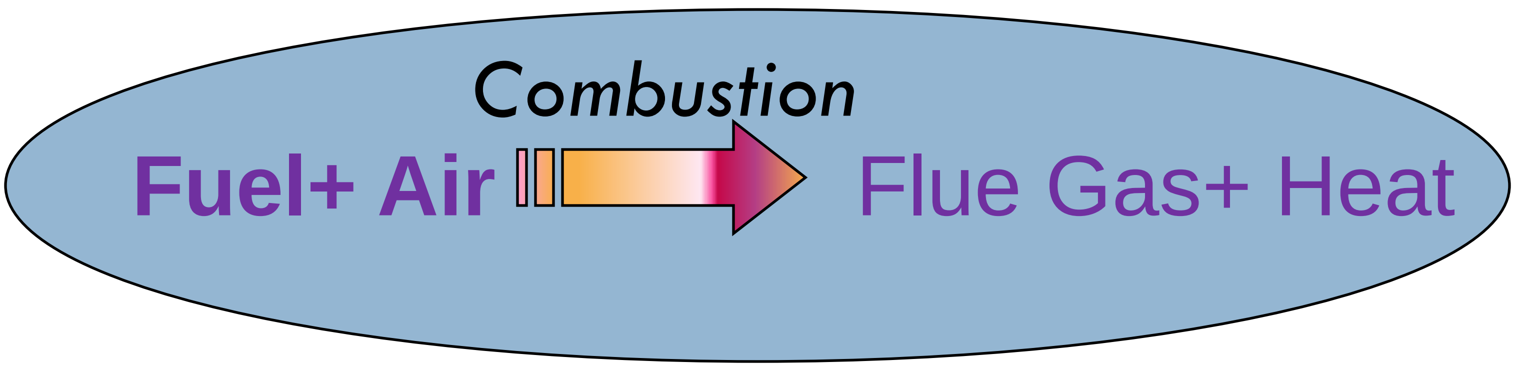
Introduction

Basics of Combustion



Introduction

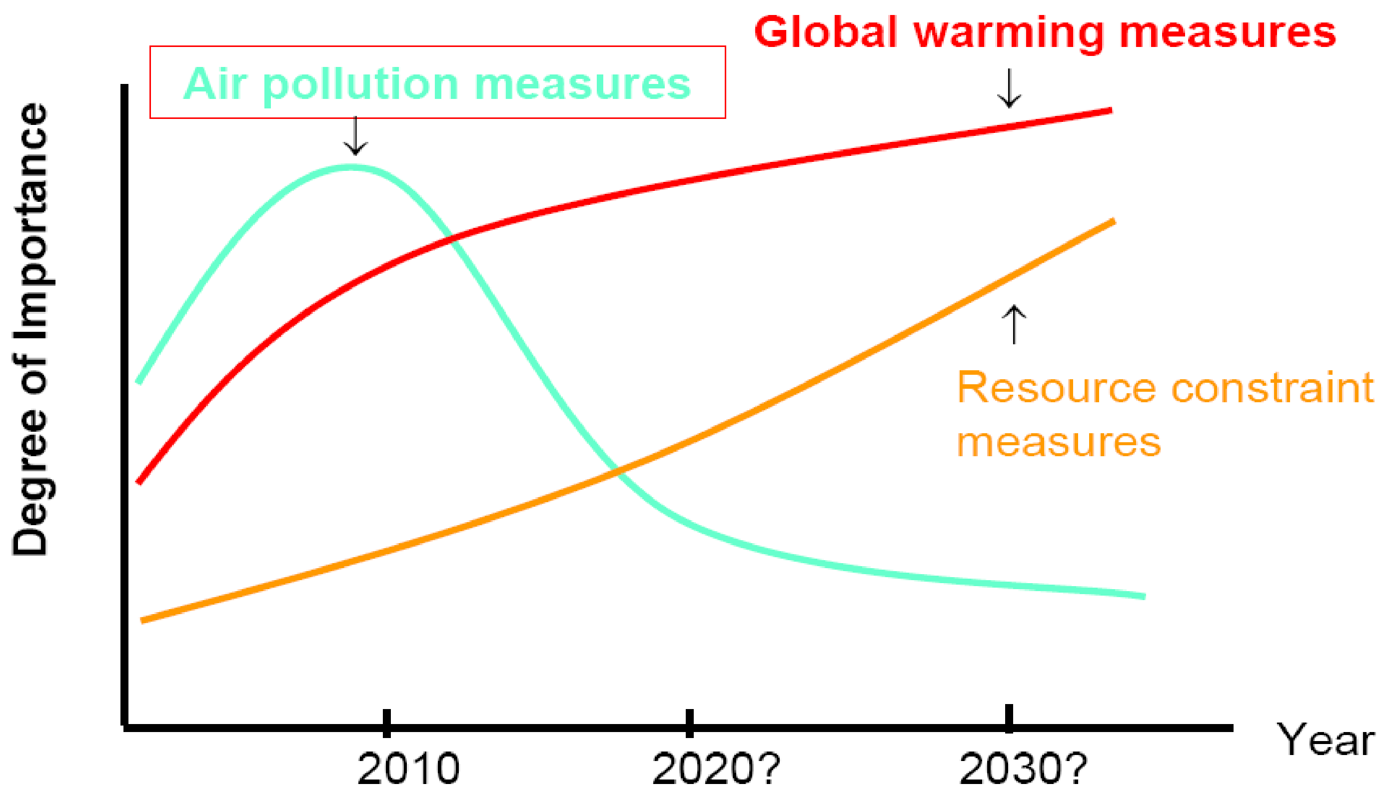
- In order to generate Heat, Combustion of Fuel are required



- Therefore the fundamental knowledge of different types of Fuel characteristics is essential in order to understand the combustion process

Introduction

- *Fuel used currently for IC engines and some of its associated aftermaths: pollution, global warming and resource constraints*

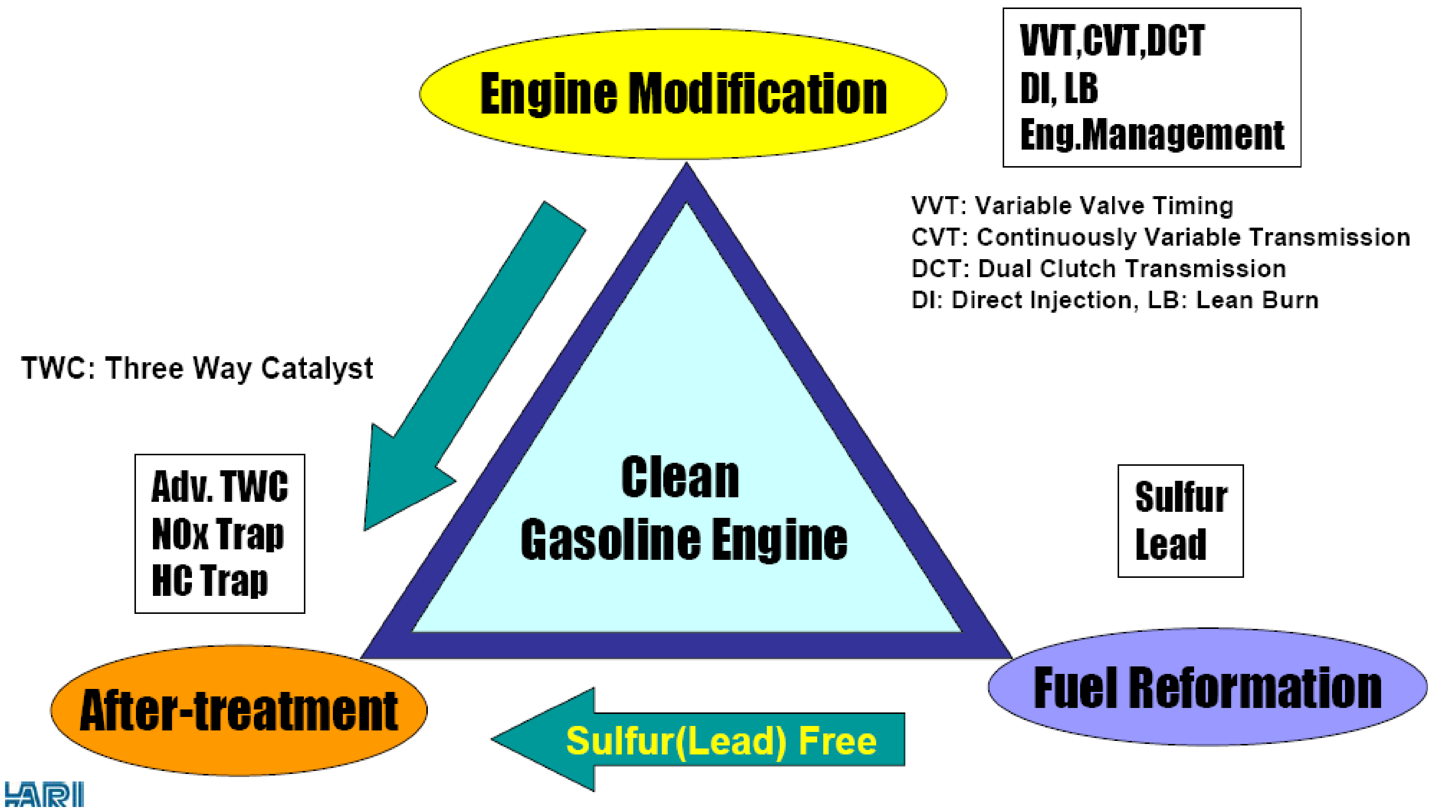


Environment & Energy Restriction

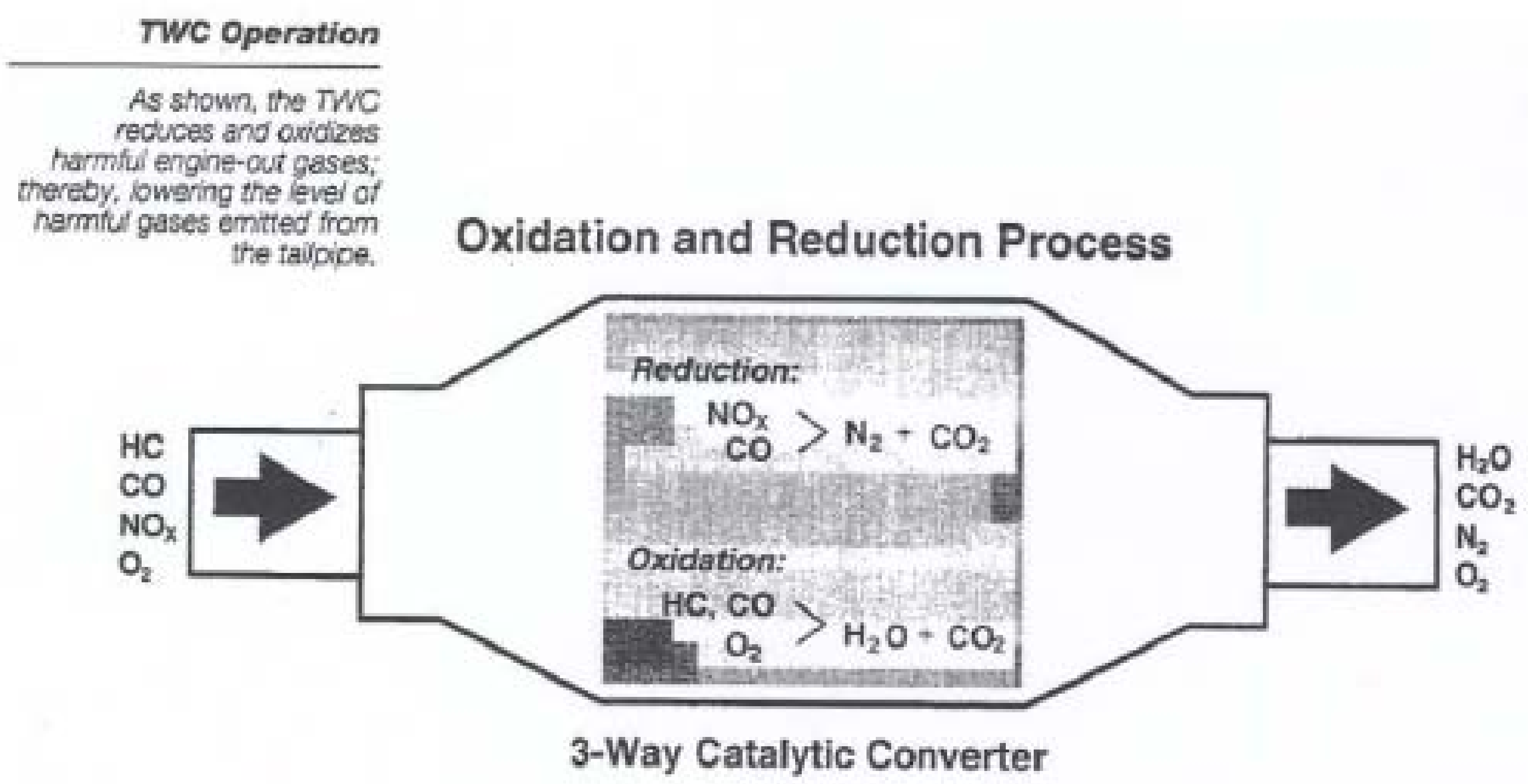
- Global warming problem
  - To minimize global warming severe reduction of CO_2 emission into the atmosphere has become universal agenda
- Air pollution problem
  - Reduction of toxic substances from vehicle has become a vital issues such as
  - Carbon monoxide (CO), Sulfur dioxide (SO_2), Nitrogen dioxide (NO_2), and Particulate matter, $PM_{2.5}$
- Resource and energy problem
  - Transportation sector's overdependence on petroleum must be reduced (adaptation of alternative fuels is necessary, etc.)

Air Pollution Issue of SI engine

The above motives can be achived through engine modification, after treatment , fuel reformation and adaptation of alternative fuel

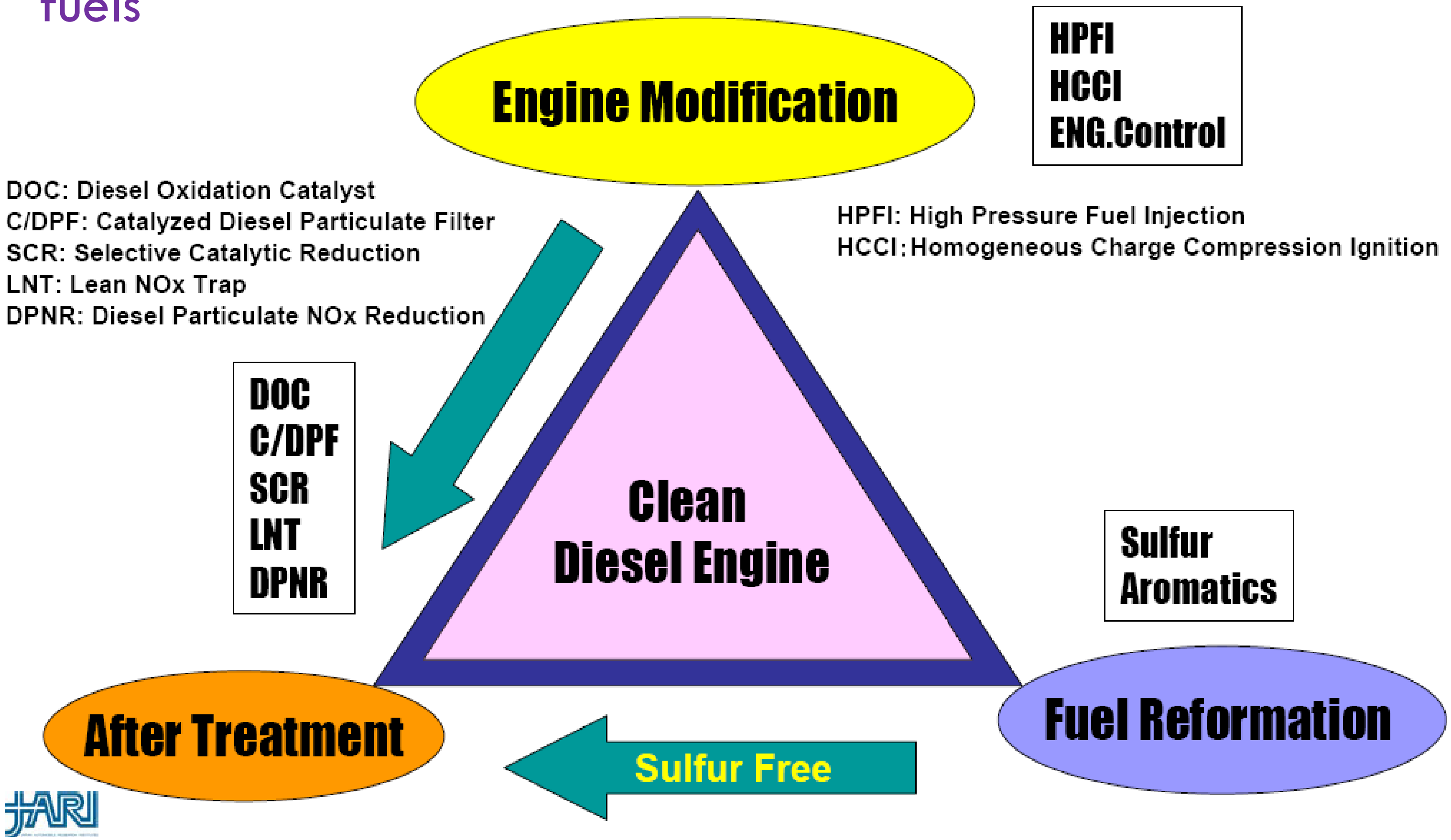


TWC convertor



Air Pollution Issue of CI Engine

The above motives can be achived through engine modification, after treatment, fuel reformation and adaptation of alternative fuels



Fuels for Engines

- IC Engines can be operated on different types of fuels
  1. Gaseous
  2. Liquid
  3. Originally solid also but now very rarely used.

  May be
  1. Naturally available or
  2. Artificially derived

Solid Fuels

- Solid fuels have little practical application at the present because of

  - Problem of handling
  - Disposing of the solid residue or ash
  - Feeding are quite cumbersome

- *Therefore this fuels have become unsuitable for I.C Engine application.*

Gaseous Fuels

- Gaseous Fuels are ideal and pose very few problems in using them in IC engine
- Main gaseous fuels for engines are
  - Natural gas – from nature
  - Liquefied Petroleum Gas - from refineries
  - Producer gas - from coal or biomass
  - Biogas - from biomass
  - Hydrogen – from many sources

Gaseous Fuels

- Advantages of Gaseous Fuels
  - Mix more homogeneously with air
  - Eliminate starting problems
- Disadvantage
  - Storage and handling Problem
- *Therefore gaseous fuels are commonly used for stationary power plants located near the source of available of the fuel.*
- *Some of the gaseous fuel can be liquefied under pressure for reducing the storage volume but this arrangement is very expensive and risky*

Natural gas

- Found compressed in porous rock and shale formations sealed in rock layer underground.
- Frequently exists near or above oil deposits.
- Is a mixture of hydrocarbons and non hydrocarbons in gaseous phase or in solution with crude oil.
- Raw gas contains mainly methane (60-90 %) plus lesser amounts of ethane, propane, butane and pentane, negligible sulfur, nitrogen, carbon dioxide and helium are present.

Natural Gas

- Natural Gas may be used as
  - Liquefied Natural Gas (LNG).
  - Compressed Natural Gas (CNG).
- Natural Gas can be made artificially called substitute, or synthetic or Supplemental Natural Gas (SNG).

Natural gas

Preparation of Natural Gas

1. Separation of liquid and gas. Liquid may be a hydrocarbon present in the gas well along with the gas.

2. Dehydration. Water is corrosive and hydrates may form which will plug the flow. Water will also reduce the calorific value of the gas.

3. Desulfurization. Presence of hydrogensulfide is undesirable. The gas is called ***sour.*** When the sulfur is removed the gas is ***sweetened.***

Natural Gas

- Composition

  90-95% methane

  0-4% nitrogen,

  4% ethane and

  1-2% propane.

Advantages of Natural Gas

- Methane is a greenhouse gas with a global warming potential approximately 4 times that of carbon dioxide.
- Its C/H ratio is lower than that of gasoline so its CO_2 emissions are 22-25% lower (54.9 compared to 71.9 g CO_2/MJ fuel).
- Has higher calorific values

Comparison of CNG with Gasoline

	Calorific Values (Kcal/kg)	Octane Number	Auto-ignition Temp (°C)
Gasoline	10, 400	92	390
Diesel	10, 200	low	280
CNG	11, 200	130	640

Natural Gas

- If an engine is switched to CNG from gasoline, the non-methane organic gases like CO and NO_x, all reduced by 30-60%.

- Toxic emissions like benzene, butadiene and aldehydes were much less than with gasoline.

- Natural gas can replace diesel fuel in heavy-duty engines with the addition of a spark ignition system.

- Engines operate at $\phi = 0.7$ giving low in-cylinder temperatures and hence low NO_x.

Natural Gas in Engines

- Heavy-duty natural gas engines are designed to meet low emission vehicle (LEV) emission standards without a catalytic converter and will meet ULEV emission standards with a catalytic converter.

- For heavy-duty applications, dual fuel operation is attractive, for buses, locomotives, ships, compressors and generators. They are operated lean to reduce NO_x.

- However, at light loads, the lean combustion conditions will degrade the combustion process increasing HC and CO emissions.

Typical Composition of Producer gas

Component	Percentage
Hydrogen	20
Carbon Monoxide	19.5
Carbon Dioxide	12.5
Methane	2
Nitrogen	46
Octane Number	100-105
Lower Heating Value	6.7 MJ/m^3

- Energy density of stoichiometric fuel-air mixture
  - **Producer gas: 2.5 MJ/m^3**
  - **Gasoline-air: 3.5 MJ/m^3**
  - **Diesel-air: 3.3 MJ/m^3**

Liquid Fuels

- The three commercial types of liquid fuels are
  - ***Benzol-*** a by product of high temperature coal carburization and consist principally of ***benzene (C_6H_6)*** ***and*** ***toluene (C_7H_8)***
  - **Alcohol-** used as a fuel after blending it with gasoline
  - **Petroleum Products-** the main fuels for IC engines (gasoline, kerosene, diesel oil)

Liquid Fuels

- In most of the modern IC engines, liquid fuels are being used, which are derivatives from liquid petroleum.

- Crude petroleum consists of
  - A mixture of *large number of hydrocarbons*
  - Small amounts of *sulphur, oxygen, nitrogen*, and
  - *Impurities* such as *water and sand*

Liquid hydrocarbon fuels

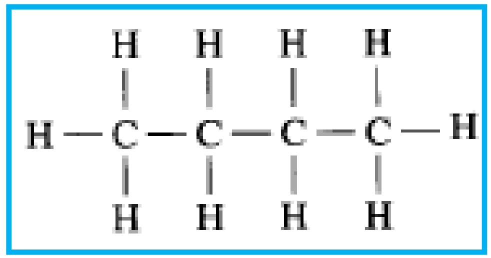
- The **basic families** of **liquid hydrocarbon fuels**, their **general formula and their molecular structure** is shown in table below

Family	General Formula	Molecular Arr.
Paraffin	C_nH_{2n+2}	Chain
Olefin	C_nH_{2n}	Chain
Diolefin	C_nH_{2n-2}	Chain
Naphthene	C_nH_{2n}	Ring
Aromatic	C_nH_{2n-4}	Ring

Paraffins (Alkanes)

- Consists of a ***straight chain (open chain)*** molecular structure like methane, ethane, propane etc

  E.g. Butane



Suffix "ane"

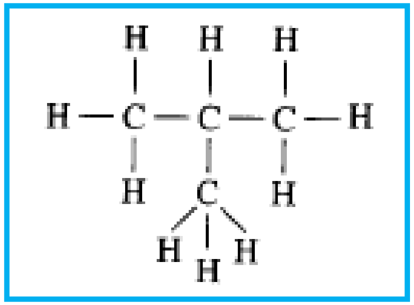
- The valence of each carbon atom is fully utilized in combining, ***by a single bond***, with other carbon atoms and with hydrogen atoms.

- They are termed as ***saturated compounds*** and characteristically ***very stable***

Branch-chain paraffin

- ***Branch-chain paraffin*** has the *same general chemical formula* as the straight-chain paraffin but *a different molecular structure* and *different physical characteristics* and are called ***isomers.***

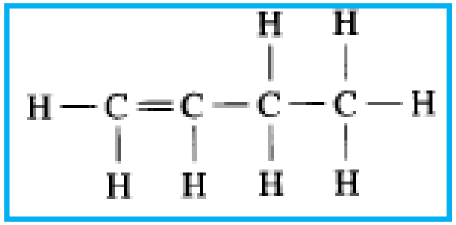
- E.g. Isobutane



- Branch chain paraffins have ***good anti-knock qualities*** when used as SI engine fuels

Olefins (Alkenes)

- Are chain compounds ***similar to paraffins***
- ***Are unsaturated*** because they contain double bond like butene
- Are ***not stable*** due to the ***presence of the double bond***
- E.g. butene

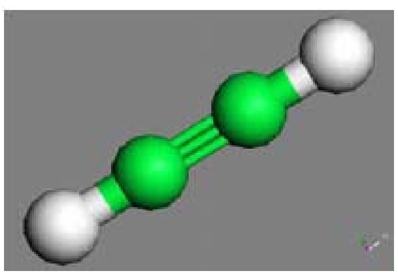


1-butene
(CH_2=CH-CH_2-CH_3)

suffix "ene"

Diolefins (Alkadiene)

- Are essentially ***olefins with two double bonds or triple bond***
- Are ***unsaturated and rather unstable***
- Tend to form gum deposits during storage by reacting with oxygen
- E.g. butadiene

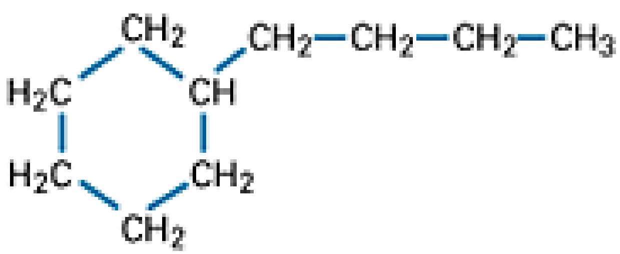


acetylene
(CH≡CH)

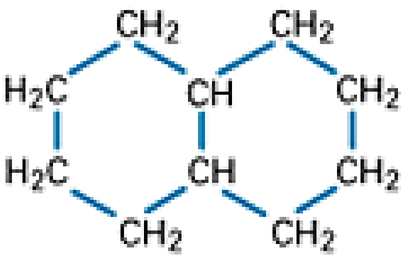
Napthenes or Cycloparaffins

- Have the same **general formula as olefins but with a ring structure**
- Are often formed as ***Cyclo-paraffins***
- ***Are saturated, and tend to be stable***

Naphthenes



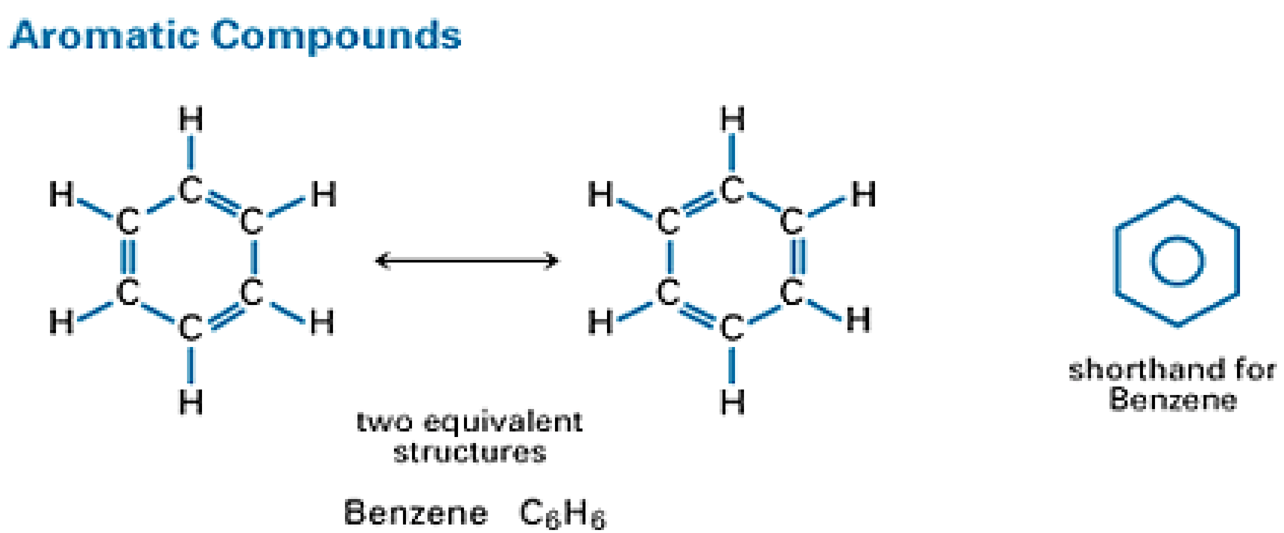
Butylcyclohexane $C_{10}H_{20}$



Decalin $C_{10}H_{18}$

Aromatics

- are *ring structure* compounds based on *the benzene ring*
- While the double bonds indicate *unsaturation*, a *peculiar nature of these bonds* causes this family *to be more stable than* the other unsaturated families
- E.g. Benzene



General Characteristics

- The above families of hydrocarbons exhibit general characteristics due to their molecular structure which are summarized below
- Normal paraffins exhibit the poorest antiknock quality when used in SI engine.
  - **But the antiknock quality improves with the increasing**
    - **number of carbon atoms and**
    - **the compactness of the molecular structure.**

- The aromatics offer the best resistance to knocking in SI Engines.
- For CI engines, the order is reversed i.e.
  - **the normal paraffins are the best fuels and**
  - **aromatics are the least desirable,**

General Characteristics

- As the number of atoms in the molecular structure increases, the boiling temperature increases.
  - Thus fuels with fewer atoms in the molecule tend to be more volatile.

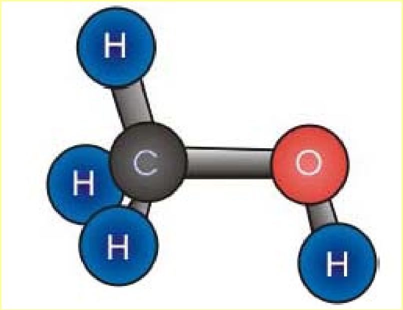
- The heating value generally increases as the proportion of hydrogen atoms to carbon atoms in the molecule increases due to the higher heating value of hydrogen than carbon.

- Thus, paraffins have the highest heating value and the aromatics the least.

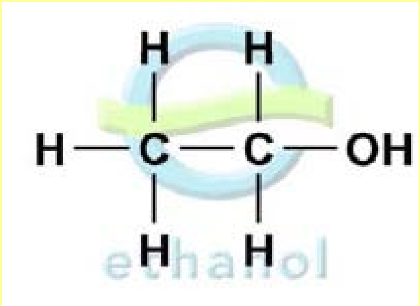
Oxygenated Fuels

- ## *Alcohol*
  - There is hydroxyl radical –OH in the molecules
  - **Example:** Methanol, Ethanol
  - Ethers – ignition improvers for diesels
  - Dimethylether (DME) – proposed as a bio diesel fuel $(CH_3)_2O$
  - Methyl tertiary butyl ether (MTBE)

$(CH_3)_3COCH_3$ – Octane improvement in gas gasoline engines



Methanol (methyl alcohol)
CH_3-OH



Ethanol (ethyl alcohol)
C_2H_5-OH

Oxygenated Fuels

Methanol CH_3OH

$$CH_4 + H_2O \rightarrow CH_3OH + H_2$$

Ethanol C_2H_5OH

$$starch + water \xrightarrow{enzyme} C_{12}H_{22}O_{11}\ (maltose)$$

$$C_{12}H_{22}O_{11} + H_2O \xrightarrow{enzyme} 2\,C_6H_{12}O_6\ \text{(glucose)}$$

$$C_6H_{12}O_6 \xrightarrow{fermentation} 2CO_2 + 2C_2H_5OH$$

CRUDE OIL

- Crude oil found in rock formations that were floors of oceans thousands of thousand years ago
- Organic matter trapped by rocks and subjected to high pressure and temperatures
- A mixture of water, dirt, and many different hydrocarbons of various molecular shapes and sizes
- Date of first oil well drilling in USA: 1859, Titusville, PA
- Most fuels are a mixture of hydrocarbons C_xH_y, typically 86 % C and 14% H by weight

Composition of typical crude oil

Carbon:	80-89%
Hydrogen:	12-14%
Nitrogen:	0.3-1.0%
Sulfur:	0.3-3.0%
Oxygen:	2.0-3.0%

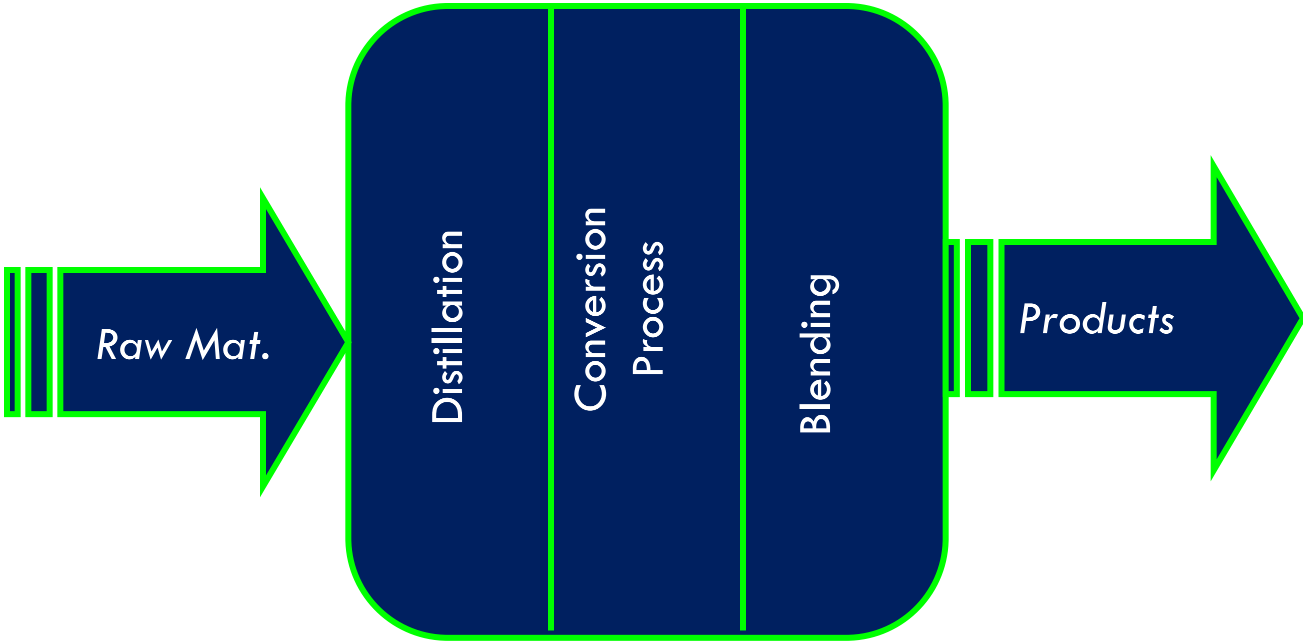
- Plus
  - oxygenated compounds like phenols, fatty acids, ketones
  - metallic elements like vanadium and nickel.

Typical Petroleum Refinery Products

Product	Boiling Range, ^{o}C
Liquefied Petroleum Gas (LPG)	-40 to 0
Motor Gasoline	30-200
Kerosene, jet fuel	170-270
Diesel Fuel	180-340
Furnace Oil	180-340
Lube Oils	340-540
Residual Fuel	340-650
Asphalt	540+
Petroleum Coke	Solid

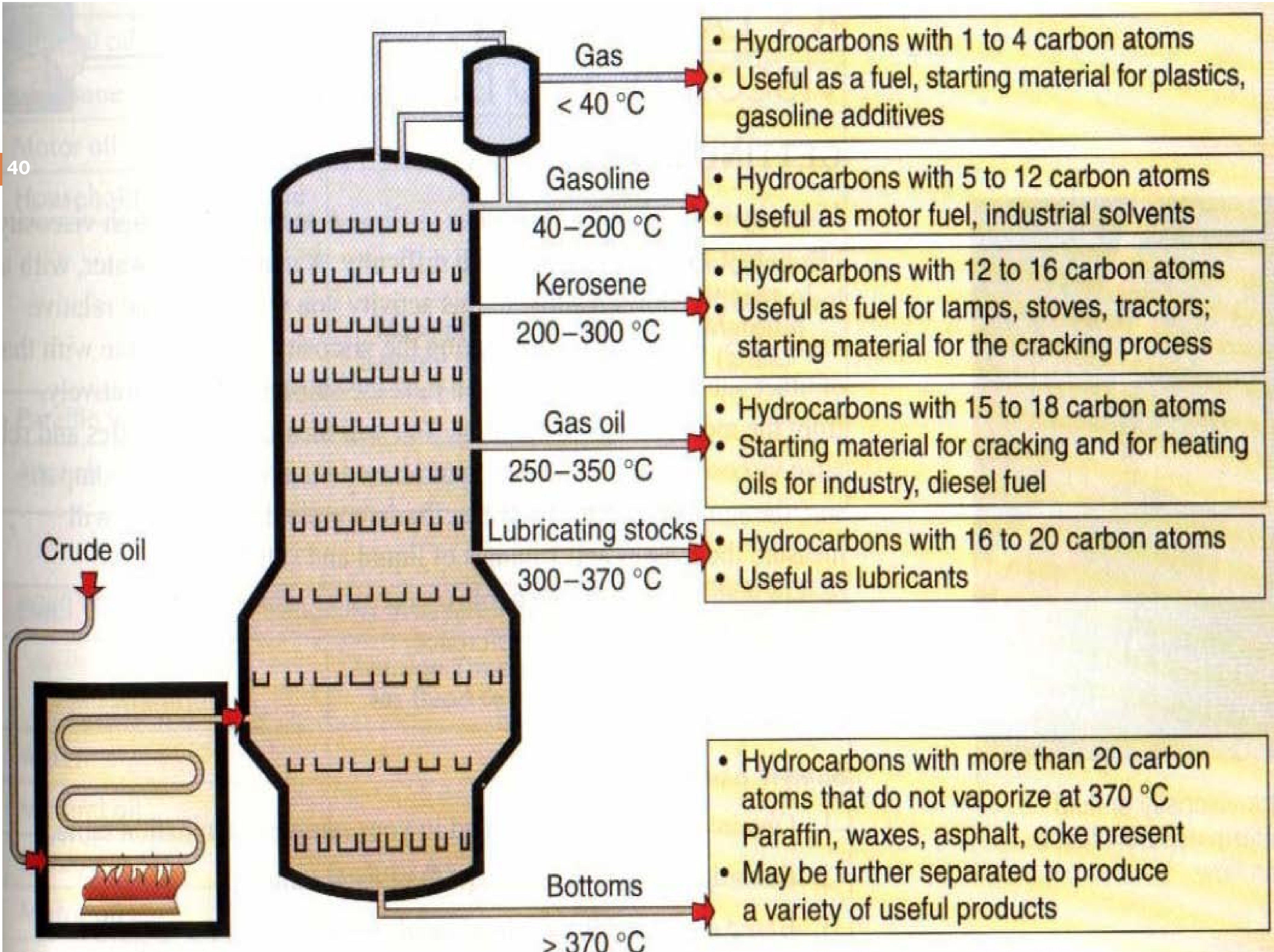
Refinery processes

1. Distillation
2. Cracking
3. Reforming
4. Polymerization
5. Alkylation
6. Isomerization
7. Hydrogenation



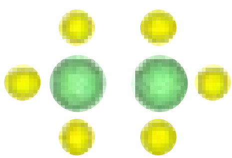
Fractional Distillation

- Separating using boiling point temperature.
- Liquid petroleum vaporized at 600^0C
- The vapor admitted to fractionating tower at its bottom
- The vapor is forced to pass upward along a labyrinth-like arrangement
- The vapor with higher boiling point condensed out at lower levels
- while those with lower boiling point moves up higher levels where they get condensed at appropriate temperature
- The factional distillation can be done
  - Atmospheric
  - Vacuum
  - Continues (Gas separation and stabilization)

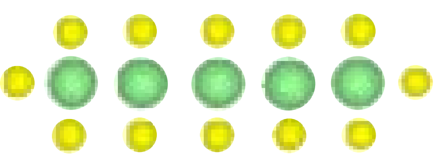

Gas
< 40 °C
• Hydrocarbons with 1 to 4 carbon atoms
• Useful as a fuel, starting material for plastics, gasoline additives
Gasoline
40–200 °C
• Hydrocarbons with 5 to 12 carbon atoms
• Useful as motor fuel, industrial solvents
Kerosene
200–300 °C
• Hydrocarbons with 12 to 16 carbon atoms
• Useful as fuel for lamps, stoves, tractors; starting material for the cracking process
Gas oil
250–350 °C
• Hydrocarbons with 15 to 18 carbon atoms
• Starting material for cracking and for heating oils for industry, diesel fuel
Lubricating stocks
300–370 °C
• Hydrocarbons with 16 to 20 carbon atoms
• Useful as lubricants
Crude oil
Bottoms
> 370 °C
• Hydrocarbons with more than 20 carbon atoms that do not vaporize at 370 °C Paraffin, waxes, asphalt, coke present
• May be further separated to produce a variety of useful products

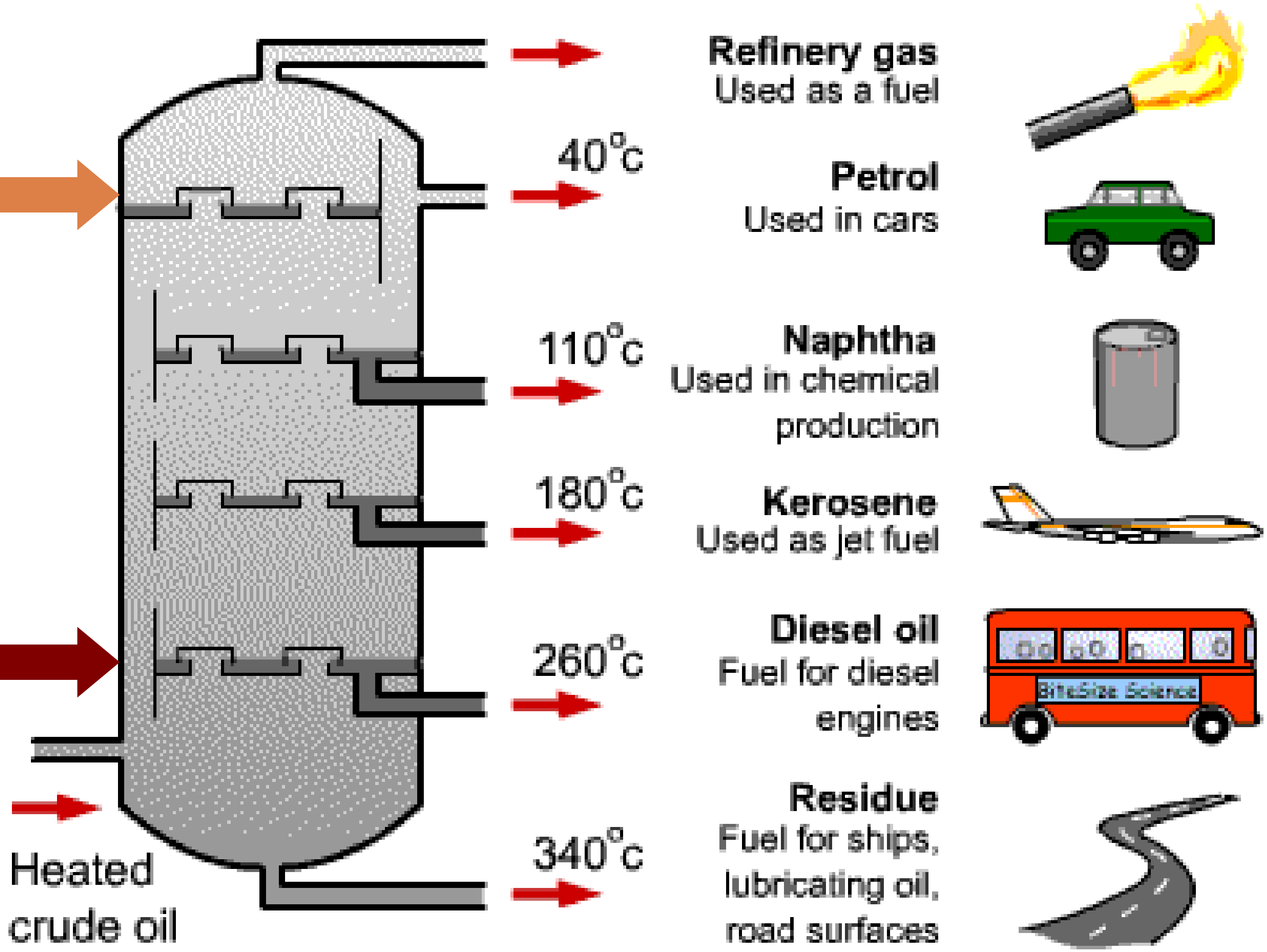
Fractional Distillation

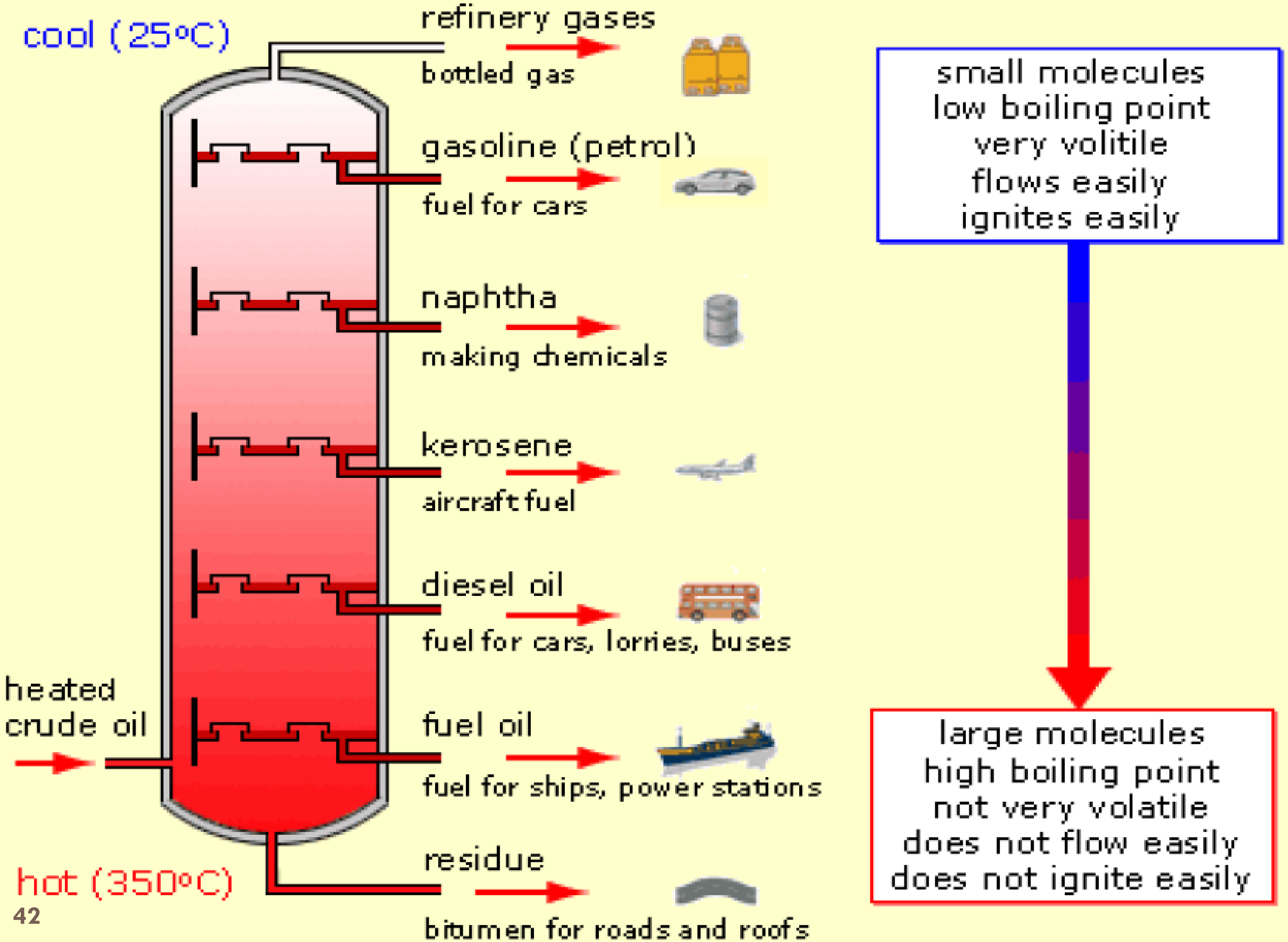
Fractions with low boiling points condense at the top



Fractions with high boiling points condense at the bottom






cool (25°C)
refinery gases
bottled gas
gasoline (petrol)
fuel for cars
naphtha
making chemicals
kerosene
aircraft fuel
diesel oil
fuel for cars, lorries, buses
heated crude oil
fuel oil
fuel for ships, power stations
residue
bitumen for roads and roofs
hot (350°C)
small molecules
low boiling point
very volitile
flows easily
ignites easily
large molecules
high boiling point
not very volatile
does not flow easily
does not ignite easily

Cracking Process

- Braking down large and complex hydrocarbons molecules into simpler compounds.
- Thermal Cracking
  - Large hydrocarbon molecules at height temperature and pressure are decomposed in to smaller, lower boiling point molecules
- Catalytic Cracking
  - Using *catalysts* at relatively lower pressure and temperature thermal cracking
    - Naphthenes are cracked to olefins and paraffins
    - Olefins to isoparaffins needed for gasoline
- Catalytic cracking gives better antiknock property for gasoline as compared to thermal cracking

Refinery Processes

- *Hydrogenation/ Hydrocracking*
  - Cracks and adds hydrogen to molecules, producing a *more saturated*, *stable*, gasoline fraction under high pressure and temperature.
- *Isomerisation*
  - Changing the relative position of the atoms within the molecule of a hydrocarbon without changing its molecular formula.
  - Converting straight chain hydrocarbons into branched isomers
  - *Example*
    - Converting n-butane in to iso-butane for alkylation
    - Conversion of n-pentane and n-hexane in to isoparaffins to ***improve knock rating of highly volatile gasoline***

Refinery Processes

- *Reforming*
  - converts saturated, low octane (low antiknock quality), hydrocarbons into higher octane product containing about 60% aromatics.
  - It doesn't increase the total gasoline volume
- *Alkylation*
  - Combines an olefin with an iso-paraffin to produce a branched chain iso-paraffin in the presence of a catalyst
  - reacts gaseous olefin streams with iso-butane to produce liquid high octane

    iso-alkanes.
  - *Example*
    - butylene + iso butane ⟷ iso-octane

      alkyation

Alternative Fuels

The Need for Alternative Fuels

- Energy Security
  - Peak Oil- the world's production of oil is close to its peak

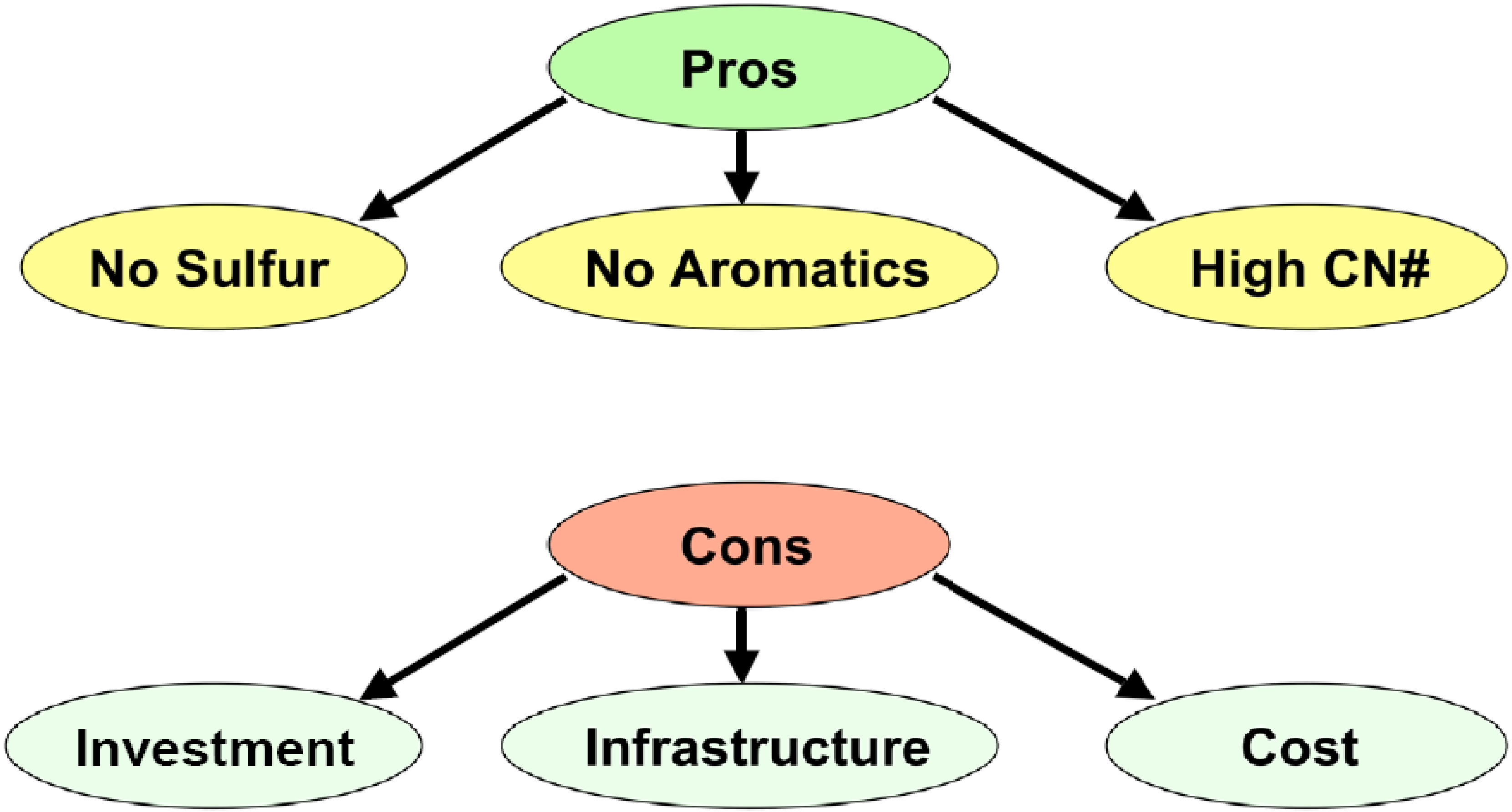
- Global warming
  - concerns and the need to reduce $C0_2$ emissions which is currently about one pound per mile for every vehicle

- *Air Pollution*
  - HC, CO, SO_2, NO_x

Types of Alternative Fuels

1. Natural gas (Methane)
2. Methane or compressed natural gas (CNG)
3. Liquefied petroleum gas (LPG) – propane, butane & ethane
4. Alcohol
   1. Methanol
   2. Ethanol
5. P-series (Ethanol, Methyl-tetra-hydro-furon, (**MTHF**), Natural gas liquids, (pentanes, Butane)
6. Bio-diesel
7. Biogas
8. Hydrogen
9. Electricity
10. Fuel Cell

Pros & Cons of Alt. Fuels



Challenges of Alt. Fuels

- Both economy and engineering reasons.
  - Cost of alternative fuel per unit of energy delivered can be greater than gasoline or diesel fuel.
  - The energy density of alternative fuels by volume is less than gasoline or diesel fuel.
- Today the alternative fuelled engines can be modified or retrofitted engines that were originally designed for gasoline or diesel fuelling.
- They are, therefore not the optimum design for the other fuels.

LPG

- Propane (C_3H_8) is a saturated paraffinic hydrocarbon. When blended with butane (C_4H_{10}) or ethane (C_2H_6), it is designated as liquefied petroleum gas (LPG).

- LPG is obtained as a by-product from:
  - The lighter hydrocarbon fractions produced during the crude oil refining.
  - The heavier components of wellhead natural gas.

- A common LPG blend is P92, which is 92% propane and 8% butane.

- Propane has an octane number of 112 (RON), so it can raise the compression ratio.

- Propane requires about 5° spark advance at lower engine speeds due to its relative low flame speed.

Natural Gas

- Like propane, natural gas is delivered to the engine through a pressure regulator, either a mixing valve located in the intake manifold, port fuel injection at about 750 kPa, or direct injection into the cylinder.

- **Bi-fuel engines**
  - Recent R&D work has included development of ***bi-fuel*** vehicles that can operated with natural gas and gasoline or natural gas and diesel.
  - One advantage of a bifuel operation is that the operating range of a vehicle is extended in comparison with a ***dedicated natural gas***.

Natural Gas

- Advantage of Natural gas
  - RON of 120, which makes it a very good SI engine fuel. One reason for this high RON is a fast flame speed. Engines can operate with a high compression ratio.
  - Low engine emissions, Less aldehydes than with methanol, and less CO_2.
  - Fuel is fairly abundant worldwide. It can be made from coal but this is more costly.

Natural Gas

Disadvantage of Natural gas

- Low energy density resulting in low engine performance.
- Low engine volumetric efficiency because it is a gaseous fuel same reason as LPG.
- Need for large pressurized fuel storage tank. Most test vehicles have a range of only 200 km. There is some safety concern with a pressurized fuel tank.
- Inconsistent fuel properties
- Refueling is slow process.

Alcohol

- Alcohols are an attractive alternative fuel because they can be obtained from a number of sources, both natural and manufactured.

- The two kinds of alcohol that seems most promising and have had the most development as engine fuel.

  - Methanol (Methy Alcohol) and

  - Ethanol (Ethyl Alcohol)

Methanol

- Pure methanol is labelled M100, and a mix of 85% methanol and 15% gasoline is labeled M85.
- M85 has an octane rating of 102.
- The cetane number of methanol is low at about 5, but it can be used in compression ignition engines with diesel fuel pilot ignition.

Ethanol

- Ethanol (C_2H_5OH) is an alcohol fuel formed from the fermentation of sugar and grain stocks, primarily sugar cane and corn, which are renewable energy source

- Ethanol is a liquid at ambient conditions, and non-toxic at low concentration.

- Gasohol (E10) is a gasoline-ethanol blend with about 10% ethanol by volume.

- E85 is a blend of 85% ethanol and 15% gasoline.

Advantage of Alcohol

- It can be obtained from a number of sources, both natural and manufactured.
- It is a high octane fuel with anti-knock index number of over 100.
- Engine using high-octane fuel can run more efficiently by using higher compression ratio.
- Generally lower overall emissions

Advantage of Alcohol

- When burned, it forms more moles of combustion, which gives higher pressure and more power in the expansion stroke.

- It has high evaporative cooling which result in a cooler intake process and compression stroke, Raised volumetric efficiency and reduced required work input.

Disadvantage of Alcohol

- Low energy content of the fuel. This mean that almost twice as much alcohol as gasoline must be burned to give the same energy input to the engine.

- But the power would be the same, as the lower air-fuel ratio needed by alcohol.

- More aldehydes in the exhaust. If as much alcohol fuel was consumed as gasoline, aldehyde emissions is a serious problem.

Disadvantage of Alcohol

- Much more corrosive than gasoline on copper, brass, aluminum, rubber, and many plastics.
- In this context, it puts some restrictions on the design and manufacturing of engines to be used with this fuel.
- Poor cold weather staring characteristics due to low vapor pressure and evaporation.
- Poor ignition characteristics in general.