Fuels

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ME 6163: Combustion Engineering
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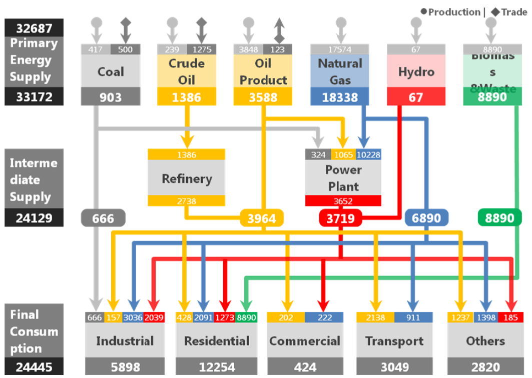
Overview

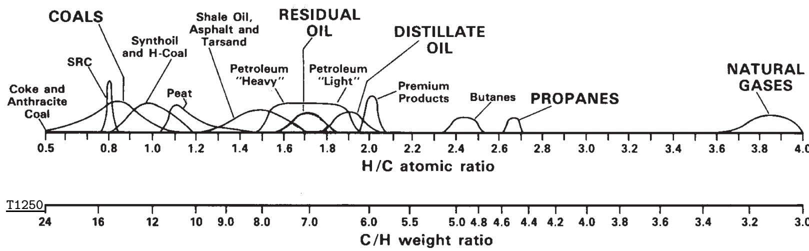
Energy Usage in Bangladesh[1]



T1249

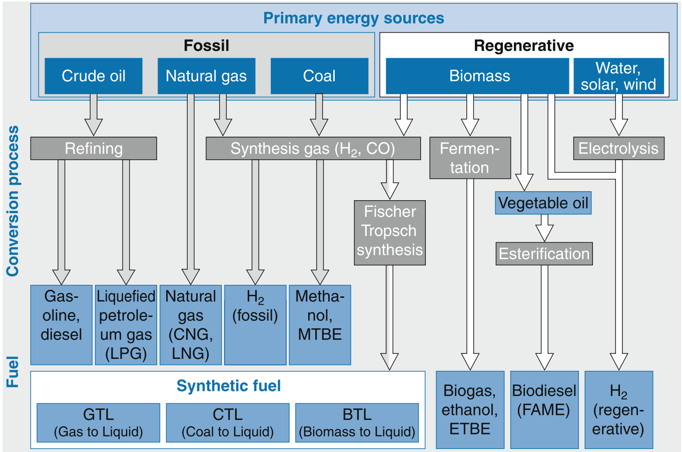
[1] *Energy Efficiency and Conservation Master Plan up to 2030* (2015). Tech. rep. Sustainable and Renewable Energy Development Authority (SREDA) and Power Division, Ministry of Power, Energy and Mineral Resources, Government of Bangladesh.

Fuels & Desirable Characteristics of Fuels



- High energy density (content)
- High heat of combustion (release)
- Good thermal stability (storage)
- Low vapour pressure (volatility)
- Non-toxicity (environmental impact)

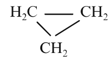
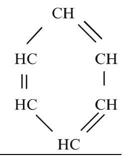
Primary Energy Sources[2]



T579

[2] K. Reif (2015). *Gasoline Engine Management: Systems and Components*. Springer.

Naming Conventions for HC Fuels[3]

Family Name	Formula	C-C	Structure	Example
Alkanes (saturated, Paraffins)	$C_\alpha H_{2\alpha+2}$	Single	Straight or branched	Ethane CH_3-CH_3
Alkenes (olefins)	$C_\alpha H_{2\alpha}$	One double bond remaining single	Straight or branched	Ethene $CH_2=CH_2$
Alkynes (Acetylenes)	$C_\alpha H_{2\alpha-2}$	One triple bond remaining single	Straight or branched	Ethyne $HC\equiv CH$
Cyclanes (cycloalkanes)	$C_\alpha H_{2\alpha}$	Single bond	Closed rings	Cyclopropane 
Aromatics (benzene family)	$C_\alpha H_{2\alpha-6}$	Aromatic bond	Closed ring	Benzene 

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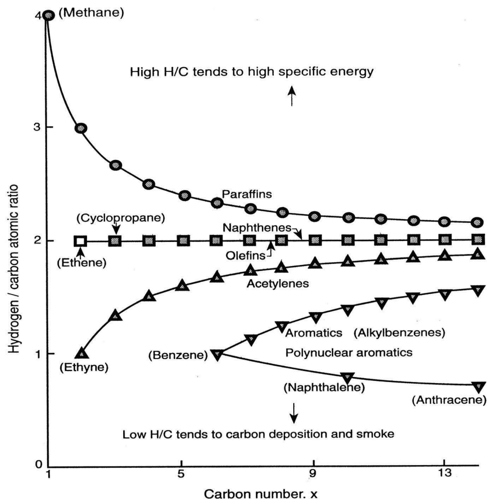
[3] S. McAllister, J. Chen, and A. Fernandez-Pello (2011). *Fundamentals of Combustion Processes*. Springer.



T1236

H:C atomic ratio of various inorganic hydrocarbon compounds[4]

[4] E. Keating (2007). *Applied Combustion*. 2nd ed. Taylor & Francis.

A comparison of some alternative fuels to the traditional petroleum-based fuels used in transportation

Fuel	Energy content kJ/L	Gasoline equivalence,* L/L-gasoline
Gasoline	31,850	1
Light diesel	33,170	0.96
Heavy diesel	35,800	0.89
LPG (Liquefied petroleum gas, primarily propane)	23,410	1.36
Ethanol (or ethyl alcohol)	29,420	1.08
Methanol (or methyl alcohol)	18,210	1.75
CNG (Compressed natural gas, primarily methane, at 200 atm)	8,080	3.94
LNG (Liquefied natural gas, primarily methane)	20,490	1.55

T301 *Amount of fuel whose energy content is equal to the energy content of 1-L gasoline.

Typical Volumetric Analysis of Some Gaseous Fuels[5]

Species	Natural Gas	LPG	Coal Producer Gas	Wood Producer Gas
CO	–	–	20%–30%	18%–25%
H_2	–	–	8%–20%	13%–15%
CH_4	80%–95%	–	0.5%–3%	1%–5%
C_2H_6	<6%	–	Trace	Trace
$>C_2H_6$[a]	<4%	100%	Trace	Trace
CO_2	<5%	–	3%–9%	5%–10%
N_2	<5%	–	50%–56%	45%–54%
H_2O	–	–	–	5%–15%

[a] Contains hydrocarbons heavier than C_2H_6

T1167

[5] G. Borman and K. Ragland (1998). *Combustion Engineering*. McGraw-Hill.

Typical Heating Value of Some Gaseous Fuels[6]

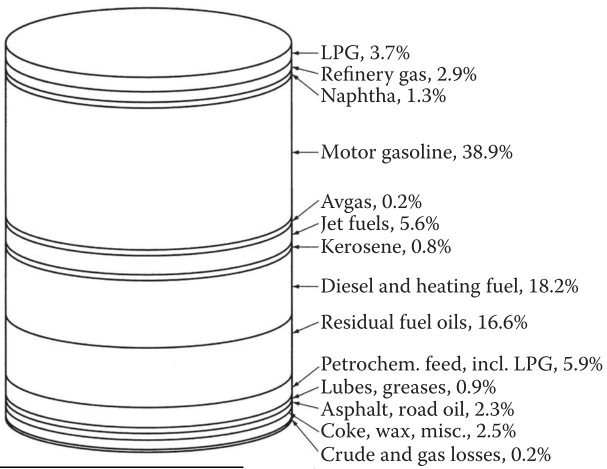
Fuel	HHV		LHV	
	(MJ/m³)[a]	MJ/kg	(MJ/m³)[a]	MJ/kg
Hydrogen (H_2)	11.7	142.2	9.9	121.2
Carbon monoxide (CO)	11.6	10.1	11.6	10.1
Methane (CH_4)	36.4	55.5	32.8	50.0
Ethane (C_2H_6)	63.8	51.9	58.4	47.8
Propane (C_3H_8)	90.8	50.4	83.6	46.4
Butane (C_4H_{10})	117	49.5	108	45.8
Ethylene (C_2H_4)	57.7	50.3	54.1	47.2
Acetylene (C_2H_2)	53.2	49.9	51.4	48.2
Propylene (C_3H_6)	84.2	48.9	78.8	45.8
Natural gas (typical)	38.3	53.5	34.6	48.3
Coal producer gas (typical)	5.2	5.3	4.3	4.4
Wood producer gas (typical)	4.8	5.1	4.0	4.2

[a] At 1 atm, 25°C

T1168

[6] G. Borman and K. Ragland (1998). *Combustion Engineering*. McGraw-Hill.

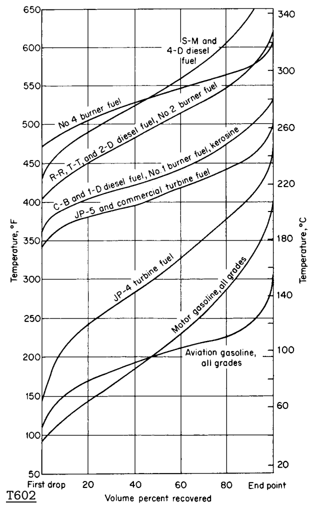
Typical Crude Oil Refinery Products[7]



T1170

[7] G. Borman and K. Ragland (1998). *Combustion Engineering*. McGraw-Hill.

Typical ASTM Petroleum Distillation Curves



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- The 10% and 90% evaporation temperatures, T_{10} and T_{90}, are used in the volatility specifications.
- T_{10}: indicates the start of vaporization, is used to characterize the cold starting behaviour,
- T_{90}: indicates the finish of vaporization, is used to characterize the possibility of unburned hydrocarbons.
- The ASTM drivability index (DI) is a measure of fuel volatility and is defined as:

$$DI = 1.5\,T_{10} + 3\,T_{50} + T_{90}$$

Typical Composition of Gasoline Fuels[8]

	Average gasoline	Gasohol	Phase 1 RFG	Phase 2 RFG
Aromatics, vol%	28.6	23.9	23.4	25.4
Olefins, vol%	10.8	8.7	8.2	4.1
Benzene, vol%	1.60	1.6	1.3	0.93
Reid vapor pressure, kPa	60-S	67-S	50-S	46
(S: summer and W: winter)	79-W	79-W	79-W	
T_{50}, K	370	367	367	367
T_{90}, K	440	431	431	418
Sulfur, mass ppm	338	305	302	31
Ethanol, vol%	0	10	4	0

T589 *Source:* Adapted from EPA 420-F-95-007.

[8] C. Ferguson and A. Kirkpatrick (2015). *Internal Combustion Engines: Applied Thermosciences*. Wiley.

Diesel Fuel Specifications (ASTM D975)[9]

	ASTM Method	No. 1-D	No. 2-D	No. 4-D
Minimum cetane number	D613	40	40	30
Minimum flash point, °C	D93	38	52	55
Cloud point, °C	D2500	Local	Local	Local
Maximum water and sediment, vol%		0.05	0.05	0.05
Maximum carbon residue	D524	0.15	0.35	
Maximum ash, wt%	D482	0.01	0.01	0.10
T_{90}, K	D86	561 max	555–611	
Kinematic viscosity at 40 °C (mm²/s)	D445	1.3–2.4	1.9–4.1	5.5–24
Maximum copper strip corrosion		No. 3	No. 3	

T590

- 1-D: is a light distillate ($\sim C_{12}H_{22}$) for cold weather.
- 2-D: is a middle distillate ($\sim C_{15}H_{25}$) diesel fuel of lower volatility and is the most common for vehicles.
- 4-D: is a heavy distillate fuel used for stationary applications.

[9] C. Ferguson and A. Kirkpatrick (2015). *Internal Combustion Engines: Applied Thermosciences*. Wiley.

Typical Properties of Automotive Fuels[10]

Property	Automotive Gasoline	No. 2 Diesel Fuel	Ethanol	B100 Biodiesel
Chemical formula	C_4 to C_{12}	C_8 to C_{25}	C_2H_5OH	C_{12} to C_{22}
Molecular weight	100–105	~200	32	~292
Specific gravity at 16°C	0.72–0.78	0.85	0.794	0.88
Kinematic viscosity at 20°C (m²/s)	0.8×10^{-6}	2.5×10^{-6}	1.4×10^{-6}	–
Boiling point range (°C)	30–225	210–235	78	182–338
Reid vapor pressure (kPa)	48–69	<2	148	<0.3
Flash point (°C)	–43	60–80	13	100–170
Autoignition temp (°C)	257	~315	423	–
Octane No. (Research)	88–98	–	109	–
Octane No. (Motor)	80–88	–	90	–
Cetane No.	<15	40–55	–	48–65
Stoichiometric air-fuel ratio by weight	14.7	14.7	9.0	13.8
Carbon content (wt %)	85–88	87	52.2	77
Hydrogen content (wt %)	12–15	13	13.1	12
Oxygen content (wt %)	2.7–3.5	0	34.7	11
Heat of vaporization (kJ/kg)	380	375	920	–
LHV (MJ/kg)	43.5	45	28	42

T1171

[10] G. Borman and K. Ragland (1998). *Combustion Engineering*. McGraw-Hill.

Octane Number

Steps to measure the octane number of a test fuel is as follows:

1. Run the CFR engine on the test fuel at either the motor or the research operating conditions.
2. Slowly increase the compression ratio until the standard amount of knock occurs.
3. At that compression ratio, run the engine on blends of the reference fuels isooctane and n-heptane.
4. The octane number is the percentage of isooctane in the blend that produces the standardized knock at that compression ratio.

Two sets of CFR engine operating conditions for engines are employed to define two octane numbers:

1. Research Octane Number (RON) (ASTM D908)
2. Motor Octane Number (MON) (ASTM D357)

Diesel Cetane Number

- The Cetane number characterizes the ability of the fuel to auto-ignite, the opposite of octane number.
- For high Cetane numbers, ignition delay is short. Hence, combustion is initiated while the fuel is being injected, so the burning rate is controlled by the rate of fuel–air mixing.
- For low Cetane numbers, fuel will not ignite until late in the injection process. Hence, fuel is well mixed so that once combustion is initiated, the burning rate is very high, causing diesel knock to occur.
- Cetane numbers for vehicular diesel range from about 40 to 55.
- The Cetane number of n-cetane is assigned a value of 100, as it is one of the fastest-igniting hydrocarbon.
- Isocetane (heptamethylnonane) ignites slowly & its CN = 15.

Typical Aviation Turbine Fuel Properties[11]

Property	Units	Jet A	Jet B
Naphthalenes	% vol max	3	3
Aromatics	% vol max	20	20
Specific gravity	°API	37–51	45–57
LHV	MJ/kg, min	42.8	42.8
Viscosity	cST at –4°F, max	8	–
Freezing point	°C, max	–40	–50
Existent gum	mg/100 mL, max	7	7
Total sulfur	wt %, max	0.3	0.3
Flash point	°C, min	38	–

T1172

[11] G. Borman and K. Ragland (1998). *Combustion Engineering*. McGraw-Hill.

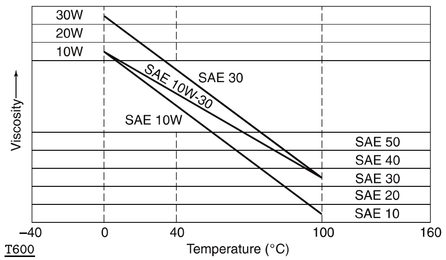
Typical Properties of Fuel Oils[12]

Fuel Grade No.	1	2	4	5	6
Property	Kerosene	Distillate	Very Light Residual	Light Residual	Residual
Color	Clear	Amber	Black	Black	Black
Specific gravity at 16°C	0.825	0.865	0.928	0.953	0.986
Kinematic viscosity at 38°C (m²/s)	1.6×10^{-6}	2.6×10^{-6}	15×10^{-6}	50×10^{-6}	360×10^{-6}
Pour point (°C)	<–17	<–18	–23	–1	19
Flash point (°C)	38	38	55	55	66
Autoignition temp. (°C)	230	260	263	–	408
Carbon (wt %)	86.5	86.4	86.1	85.5	85.7
Carbon residue (wt %)	Trace	Trace	2.5	5.0	12.0
Hydrogen (wt %)	13.2	12.7	11.9	11.7	10.5
Oxygen (wt %)	0.01	0.04	0.27	0.3	0.38–0.64
Ash (wt %)	–	<0.01	0.02	0.03	0.04
HHV (MJ/kg)	46.2	45.4	43.8	43.2	42.4

T1173

[12] G. Borman and K. Ragland (1998). *Combustion Engineering*. McGraw-Hill.

Lubricants: Engine Oil Viscosity[13]



T600

$$\mu = C_1 \exp\left[\frac{C_2}{1.8T(^\circ C) + 127}\right]$$

SAE grade	C_1 (N s/m²)	C_2 (°C)
10	1.09×10^{-4}	1157.5
20	9.38×10^{-5}	1271.6
30	9.73×10^{-5}	1360.0
40	8.35×10^{-5}	1474.4
50	1.17×10^{-4}	1509.6
60	1.29×10^{-4}	1564.0

T601

- Engine oil reduces the friction between the principal moving parts of an engine.
- It also acts as a coolant for the pistons, rings, and bearings, to enhance the rings combustion seal, to control engine wear or corrosion, and to remove impurities from lubricated regions.

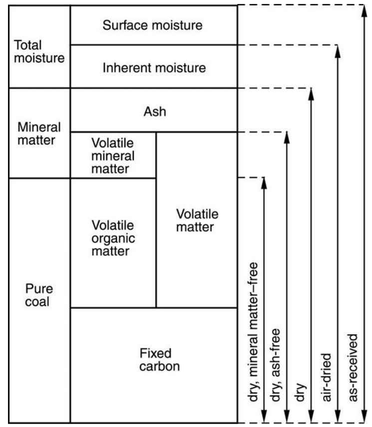
[13] C. Ferguson and A. Kirkpatrick (2015). *Internal Combustion Engines: Applied Thermosciences*. Wiley.

Coal Ranking & Analysis

ASTM (American Society for Testing Materials) Classifications:

1. Anthracitic coals (class I)
2. Bituminous coals (class II)
3. Subbituminous coals (class III)
4. Lignitic coals (class IV)

Coal Composition[14]



T1239

[14] B. Miller (2011). *Clean Coal Engineering Technology*. Elsevier Science.

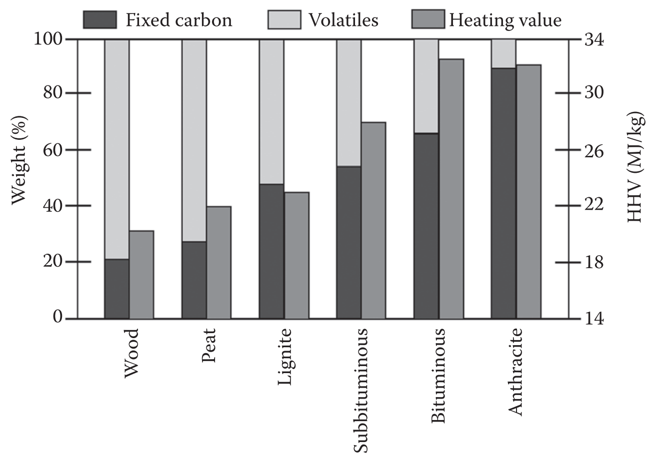
Typical Compositions of Solid Fuels[15]

Fuel	Oxygen (Dry, Ash-free)	Moisture (Ash-free)	Ash (Dry)
Wood	45%	15%–50%	0.1%–1.0%
Peat	35%	90%	1%–10%
Lignite coal	25%	30%	>5%
Bituminous coal	5%	5%	>5%
Anthracite coal	2%	4%	>5%
Refuse-derived fuel	40%	24%	10%–15%

T1175

[15] G. Borman and K. Ragland (1998). *Combustion Engineering*. McGraw-Hill.

Typical Properties of Solid Fuels[16]



T1177

[16] G. Borman and K. Ragland (1998). *Combustion Engineering*. McGraw-Hill.

Typical Properties of Solid Fuels (Dry, Ash-free)[17]

Fuel Type	Wood	Peat	Lignite	Bituminous Coal	Refuse-Derived Fuel
Proximate analysis, wt %					
Volatile matter	81	65	55	40	85
Fixed carbon	19	35	45	60	15
Ultimate analysis, wt %					
Hydrogen	6	6	5	5	7
Carbon	50	55	68	78	52
Sulfur	0.1	0.4	1	2	0.3
Nitrogen	0.1	0.6	1	2	0.7
Oxygen	44	38	25	13	40
HHV					
(Btu/lb_m)	8700	9500	10,700	14,000	9700
(MJ/kg)	20.2	22.1	24.9	32.5	22.5

T1178

[17] G. Borman and K. Ragland (1998). *Combustion Engineering*. McGraw-Hill.

Typical Properties of Selected Solid Biofuels (Dry Basis)[18]

Biomass	C	H	O	N	S	Ash	HHV (MJ/kg)
Kelp, giant brown, Monterey	26.6	3.7	20.2	2.6	1.1	45.8	10.3
Mango wood	46.2	6.1	44.4	0.3	0.0	3.0	19.2
Maple	50.6	6	41.7	0.3	0.0	1.4	19.9
Oak	49.9	5.9	41.8	0.3	0.0	2.1	19.4
Pine	51.4	6.2	42.1	0.1	0.1	0.1	20.3
Pine, bark	52.3	5.8	38.8	0.2	0.0	2.9	20.4
Poplar, hybrid	50.2	6.1	40.4	0.6	0.0	2.7	19.0
Rice hulls	38.5	5.7	39.8	0.5	0.0	15.5	15.3
Rice straw	39.2	5.1	35.8	0.6	0.1	19.2	15.2
Sudan grass	45.0	5.5	39.6	1.2	0.0	8.7	17.4
Switchgrass, Dakota Leaf, MN	47.4	5.8	42.4	0.7	0.1	3.6	18.6

T1176

[18] G. Borman and K. Ragland (1998). *Combustion Engineering*. McGraw-Hill.

References I

- *Energy Efficiency and Conservation Master Plan up to 2030* (2015). Tech. rep. Sustainable and Renewable Energy Development Authority (SREDA) and Power Division, Ministry of Power, Energy and Mineral Resources, Government of Bangladesh.
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