FUEL PROPERTIES

- **Gross/Higher and Net/Lower Heating Value**
- **Ultimate Analysis**
- **Proximate Analysis**
- **Fly Ash Analysis**
- **Hardgrove Grindability Index**
- **Density**
- **Viscosity**
- **Flash Point and Pour Point**
- **Metal Content**

HIGHER & LOWER HEATING VALUE

- When a hydrocarbon fuel is burned, it produces heat as well as water vapor. Since the combustion gases and water vapor is released to the atmosphere, its latent heat of vaporization is never recovered.

- The actual energy that could then be extracted by the heat/power equipment is the lower or net heating value. It is computed by subtracting from the higher or gross heating value the latent heat of the water vapor not recovered:

LHV = **HHV** – 1030 **[%H_2/100** x 8.94] in Btu/lb.

- The % difference for solid, liquid, gas and biomass fuels is shown in the following slide:

HIGHER & LOWER HEATING VALUE

Fuel	GHV Btu/lb	% Hydrogen	NHV Btu/lb	% Difference	Average Difference
Solid Fuels					
Lignite	7,050	6.70	6,433	9.59	
Sub-Bituminous	8,710	6.40	8,121	7.26	
Bituminous	11,630	5.74	11,101	4.76	
Anthracite	12,750	2.50	12,520	1.84	
Orimulsion	13,330	10.28	12,383	7.64	
China	10,740	3.86	10,385	3.42	
Australia	9,660	3.50	9,338	3.45	
Indonesian	11,050	6.37	10,463	5.61	
Semirara	8,800	2.48	8,572	2.66	
Petroleum Coke	14,320	3.58	13,990	2.36	4.86
Liquid Fuels					
Gasoline	20,500	15.40	19,082	7.43	
Kerosene	19,800	15.30	18,391	7.66	
Diesel	19,650	13.00	18,453	6.49	
Light Fuel Oil	19,670	12.00	18,565	5.95	
Medium Fuel Oil	18,400	10.33	17,449	5.45	
Heavy Fuel Oil	17,410	12.40	16,268	7.02	6.67
Gaseous Fuels					
LPG	21,180	17.57	19,562	8.27	
Malampaya NG	20,754	21.50	18,774	10.55	
US (Pa.) NG	23,170	23.53	21,003	10.32	9.71
Biomass Fuels					
Wood Wastes	3,591	6.20	3,020	18.90	
Bagasse	4,000	2.81	3,741	6.92	
Methanol	6,600	12.58	5,442	21.29	
Ethanol	12,800	13.13	11,591	10.43	
Coconut Oil	15,748	10.87	14,747	6.79	12.87

EFFICIENCY & HEATING VALUE

- When a manufacturer quotes the thermal efficiency of a heat/power generating equipment, care must be made when comparing efficiencies among technologies and manufacturers.
- Thermal efficiency = (Power Output) / (Heat Input)
- When the heat input energy is based on higher or gross heating value, the quoted thermal efficiency is computed to be **lower.**
- When the heat input energy is based on lower or net heating value, the quoted thermal efficiency is **higher → hence be careful**.
- The % gain or savings may be magnified when comparing the two efficiencies of different basis.

ULTIMATE ANALYSIS

- **Ultimate analysis** - ASTM D3176
- Measures carbon (C), hydrogen (H), sulfur (S), oxygen (O), and nitrogen (N) content
- Together with heating value, it is used in combustion calculations to determine fuel rates, combustion air, heat release rates, boiler performance and sulfur dioxide and carbon dioxide emissions from the power plant
- Used to quantify the chemicals or reagents or sorbents like lime stone used in reducing sulfur emissions.

PROXIMATE ANALYSIS

- **Proximate analysis** - ASTM D3172
- Measures volatile matter (VM), fixed carbon (FC) and ash
- Amount of VM indicates ease of ignition and whether supplemental flame stabilizing fuel is required
- High ash *increases cost* of handling and shipping, *raises risk* of not meeting revenue target due to greater downtimes.
- VM and FC, excluding ash, are two indicators of coal rank (I.1 to I.3, II.1 to II.5, III.1 to III.3, IV.1 to IV.2)

HARDGROVE GRINDABILITY INDEX (HGI)

- **Hardgrove Grindability Index** - ASTM D409
- Developed by Babcock & Wilcox
- An empirical measure of the relative ease with which **coal** can be pulverized and has been used for the past 30 years to evaluate the grindability of coals
- Method involves grinding a 50g of air-dried 16x30 mesh test coal in a small ball-and-race mill operated at 60 rpm and the quantity of material that passes a 200 mesh screen is measured.

HARDGROVE GRINDABILITY INDEX (2)

- From a **calibration curve** relating −200 mesh material to a standard sample from US DOE, the Hardgrove Grindability Index (HGI) is determined.
- Pulverizer manufacturers have developed correlations relating **HGI** to **pulverizer capacity** at desired levels of fineness.
- A difficult to grind or to pulverize coal *adds risk of frequent downtime* on pulverizing and size reduction equipment; *adds risk of not meeting revenue target* plus added operating expense.

ASH ANALYSIS

- **Elemental ash analysis** - sample prepared under ASTM D3174
- Measured using atomic absorption, ASTM D3682, reported as oxides: silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), titanium dioxide (TiO_2), ferric hydroxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO), sodium oxide (Na_2O) and potassium oxide (K_2O).
- Permits calculation of **fouling** and **slagging indices** and **slag viscosity** versus **temperature relationships**.
- A high fouling/slagging index and slag viscosity *adds difficulties* to smooth operation and *leads to downtimes* and added costs and lower revenues.

FUSION TEMPERATURE

- **Coal ash fusion temperatures** - determined from cones of ash prepared and heated in accordance with ASTM D1857. The temperatures at which the cones deform to specific shapes are determined in oxidizing and reducing atmospheres.

- Fusion temperatures provide **ash melting characteristics** and are used for classifying the **slagging potentials** of the lignitic-type ashes.

- **Sodium, potassium and other alkali metals** are major contributors to the **fouling tendencies** of **coal ash**.

DENSITY AND GRAVITY

- **Solid fuels -** the bulk density is the mass of fuel per unit volume, e.g. lb/ft3, kg/m3.

- **Liquid fuels -** petroleum industry uses the **API** (American Petroleum Institute) gravity scale to determine the relative density of oil; relationship between API gravity and specific gravity (**SG**) is:

  API = 141.5 / (**SG** at 60/60F) – 131.5

  Conversely, the **SG** is given by (for water density is 1.0 kg/liter):

  SG = 141.5 / (**API** + 131.5)

  = (density of oil at 60F) / (density of water at 60F)

  or (density of oil at 60F) = **SG** * (density of water at 60F)

- **Gaseous fuels -** specific gravity is given by (for air, density is 1.2263 kg/m3):

  SG = (density of gas) / (density of air)

  or (density of gas) = **SG** * (density of air)

PROPERTIES OF SOLID FUELS - COAL

LHV=HHV-10.30*%H*8.94	Anthracite	Bituminous	Sub-bituminous	Lignite
HHV, btu/lb	12,750	11,630	8,710	7,050
LHV, btu/lb	12,520	11,105	8,121	6,433
%C dry basis	79.8	65.8	49.7	41.3
%H	2.5	5.7	6.4	6.7
%S	0.6	0.5	0.4	0.4
%O	7.3	18.1	31.9	42.6
%N	0.8	1.1	0.8	0.7
%ASH	9.0	8.8	10.8	8.3
%H20	6.0	7.9	21.9	34.0
%Fixed Carbon	83.1	50.7	51.2	45.3
%Volatile Matter	7.9	40.5	38.0	46.4
%Ash	9.0	8.8	10.8	8.3
ASH FUSION TEMP. F	Initial Deformation, Oxidizing	2,560	2,180	2,160
% SiO_2	51.0	50.6	32.6	29.8
% Al_2O_3	34.0	24.6	13.4	10.0
% Fe_2O_3	3.5	17.2	7.5	9.0
% TiO_2	2.4	1.1	1.6	0.4
% CaO	0.6	1.1	15.1	19.0
%MgO	0.3	0.6	4.3	5.0
% Others (Balance)	8.2	4.8	25.5	26.8
Remarks:	hard, not suitable for power generation	burn easily especially when pulverized	burn well, suitable for power generation	low carbon content, not economical to transport

PROPERTIES OF COAL-WATER, ASIAN & COKE

LHV=HHV-10.30*%H*8.94	Orimulsion	Indonesian	Semirara	Petroleum Coke
HHV, btu/lb	13,330	11,050	8300 - 9300	14,320
LHV, btu/lb	12,383	10,463	8072 - 9072	13,990
%C dry basis	84.51	63.43	65.81	88.46
%H	10.28	6.37	2.48	3.58
%S	4.08	0.16	1.55	6.41
%O	0.28	9.65	20.38	0.01
%N	0.70	1.67	1.03	1.00
%ASH	0.14	18.71	8.75	0.54
%H20	29.0	8.0	25.0	7.0
%Fixed Carbon			24.0 - 40.0	87.5 - 93.5
%Volatile Matter			33.5 - 44.0	6.0 - 12.0
%Ash	0.14	18.71	8.75	0.54
Hardgrove Grind. Index			40 - 50	
Density, kg/liter	0.991 - 1.013			
Viscosity, 100/s	750 max			
Flash Point, C	> 90			
Pour Point, C	> 3			
Vanadium, ppm wt	360 max			500 - 3000
Sodium, ppm wt	60 max			
Nickel, ppm wt	80 max			
Magnesium, ppm wt	370 max			
Remarks:	Coal-Water mixture	Low-Sulfur	Medium-Sulfur	High-Sulfur

PROPERTIES OF SELECTED COALS

LHV=HHV-10.30*%H*8.94	China	Australia	South Africa	Indonesia	USA (Ohio)
HHV, btu/lb as received	10,740	9,660	12,170	9,840	12,970
LHV, btu/lb	10,385	9,338	11,756	9,460	12,525
%C wet basis	62.67	56.60	69.70	56.53	70.15
%H	3.86	3.50	4.50	4.13	4.83
%S	0.46	0.35	0.70	0.21	2.18
%O	10.34	7.43	9.10	12.58	7.49
%N	0.83	1.22	1.60	0.88	1.52
%ASH	4.71	24.00	10.10	1.77	8.63
%H20	17.1	6.9	4.3	23.9	5.2
%Fixed Carbon	47.2	44.3	50.3	28.8	48.1
%Volatile Matter	30.9	24.8	35.3	45.6	38.1
%Ash	4.71	24.00	10.10	1.77	8.63
ASH Analysis:					
% SiO2	22.7	57.9	44.0	71.4	50.6
% Al2O3	9.0	32.8	32.7	13.3	24.6
% Fe2O3	15.7	6.2	4.6	7.0	17.2
% CaO	28.9	0.6	5.7	2.9	1.1
% Others (Balance)	23.7	2.5	13.0	5.4	6.5
Proven Reserves, M tonnes	114,500	90,400	55,333	5,220	246,643
Anthracit & Bituminous	62,200	47,300	55,333	770	111,338
Sub-Bituminous & Lignite	52,300	43,100	na	4,450	135,305
Net Exports, M short tons	43.11	178.30	85.15	59.21	53.96
Production (1999)	1,118.00	321.00	248.00	71.00	1,099.00
Consumption (1999)	1,075.00	142.00	163.00	12.00	1,045.00
Life Time Remaining, years	113	310	246	81	247

PROPERTIES OF LIQUID FUELS

LHV=HHV-10.30*%H*8.94	LPG	Gasoline	Kerosene	Diesel (Gas Oil)
HHV, btu/lb	21,180	20,500	19,800	19,650
LHV, btu/lb	19,562	19,082	18,391	18,453
%C dry basis	82.43	84.50	84.70	85.50
%H	17.57	15.40	15.30	13.00
%S				0.80
%O				
%N				
%ASH				
	Light Fuel Oil	**Medium Fuel Oil**	**Heavy Fuel Oil**	**Coconut Oil**
HHV, btu/lb	19,670	18,400	17,410	15,748
LHV, btu/lb	18,565	17,449	16,268	14,747
%C dry basis	85.60	87.78	87.70	76.28
%H	12.00	10.33	12.40	10.87
%S	0.40	1.16	1.10	
%O	0.60	0.50		12.82
%N	0.50	0.14		
%ASH	0.90	0.00	1.80	0.00
	Naphtha	**Avgas**	**Methanol**	**Ethanol**
HHV, btu/lb	20,620	20,950	6,600	12,800
LHV, btu/lb			5,442	11,591
%C dry basis			37.48	52.14
%H			12.58	13.13
%S				
%O			49.94	34.73
%N				
%ASH			0.00	0.00

PROPERTIES OF FUEL OILS

LHV=HHV-10.30*%H*8.94	No. 1	No. 2	No. 4	No. 5
HHV, btu/lb	19,680	19,750	19,400	19,020
LHV, btu/lb	18,382	18,470	8072 - 9072	17,915
%C by wt	86.70	88.20	89.20	89.20
%H	14.10	13.90	13.00	12.00
%S	0.50	1.00	2.00	3.00
%O				
%N	0.10	0.10		
%ASH			0.10	0.10
Water & Sediment, % vol		0.10	1.00	1.00
Gravity:				
Deg API	40 - 44	28 - 40	15 - 30	14 - 22
Density, kg/liter	0.825 - 0.806	0.887 - 0.825	0.966 - 0.876	0.973 - 0.922
Flash Point, C				
Pour Point, C	-18 to -46	-18 to -40	-23 to 10	-23 to 27
Viscosity, 100/s at 100F	1.4 - 2.2	1.9 - 3.0	10.5 - 65	65 - 200
SUS at 100F		32 - 38	60 - 300	
SSF at 122F				20 - 40
Vanadium, ppm wt				
Sodium, ppm wt				
Nickel, ppm wt				
Magnesium, ppm wt				
Remarks:	Distillate fuel typically clean premium steam generation fuel heating oil	Distillate fuel typically clean premium steam generation fuel heating oil	Blend of residuel & light distillate less viscous easy to handle no heating	May require heating at ambient temp moderate sulfur

KINEMATIC VISCOSITY

- **Kinematic viscosity** - measure of the resistive flow of a fluid under the influence of gravity
- If one fluid takes 200 seconds to complete its flow and another fluid takes 400 seconds, the second fluid is twice as viscous as the first on a kinematic viscosity scale.
- Other obsolete units of kinematic viscosity are Saybolt Universal Seconds (SUS) and Saybolt Furol Seconds (SFS). These units can be converted to centi-Stokes by following instructions in ASTM D2161.

DYNAMIC VISCOSITY

- **Absolute (dynamic, simple) viscosity** - the product of kinematic viscosity and fluid density:

  Absolute viscosity = Kinematic viscosity x density

- The SI unit of kinematic viscosity is **centi-Stoke** (**cSt**) = 1 mm^2/s.
- The SI unit of absolute viscosity is **centi-Poise** (**cP**) = 1 milli-Pascal-second = 1 mPa-s.
- A *highly viscous fuel*, especially at ambient temperature requires fuel tank heating, thus adding operating costs and possibility of downtime should equipment fail.

FLASH POINT TEMPERATURE

- **Flash Point** - temperature at which vapor given off will ignite when an external flame is applied under specified test conditions
- Flash point is defined to *minimize fire risk during normal storage and handling*.
- Even when residual fuels are at a temperature below their measured flash point, they are capable of producing light hydrocarbons in the tank headspace, such that the vapor composition may be near to or within the *flammable range*.
- **Naphtha** is highly volatile and its temperature during storage and transfer must be monitored for safety considerations.

POUR POINT TEMPERATURE

- **Pour Point** - lowest temperature at which the fuel will pour or flow when chilled under prescribed test conditions.
- **Bunker fuels** originating from a complex refinery generally have pour points below 5 C.
- If a high pour point fuel is received, it would normally require external heating to keep it flowing.
- A *low pour point fuel is desirable* since it is easier to handle, transfer and feed.
- A *high pour point fuel needs to be heated* for it to pour or flow; adds cost to operation and downtime should heating equipment fail.

HEAVY METALS

- **Vanadium** - one of the metals found in most crudes and fuel oils; some vanadium oxides formed during combustion, particularly in the presence of sodium, have critical melting temperatures which may lead to *deposit formation in diesel engines, turbochargers, and boilers of steam turbine*.

- **Alkali metals – sodium and potassium –** long been associated with fouling tendencies of coal ash; vaporize in furnace and react with sulfur in flue gas and form *bonded deposits on convection heating surface*.

PROPERTIES OF SELECTED NATURAL GAS

LHV=HHV-10.30*%H*8.94	**Malampaya**	**US (Pa.)**	**US (S.C.)**	**US (Ohio)**
HHV, btu/lb	20,754	23,170	22,904	22,077
LHV, btu/lb	18,797	21,003	20,758	19,941
Specific Gravity rel. to air		0.636	0.636	0.567
%C by weight	69.73	75.25	74.72	69.12
%H	21.25	23.53	23.30	23.20
%S	0.02			0.34
%O	8.12		1.22	1.58
%N	0.86	1.22	0.76	5.76
%ASH	0.00			
% Moisture	0.03			
% CH4 by volume	88.02	83.40	84.00	93.33
% C2H4			0.25	
% C2H6	3.87	15.80	14.80	
% C3H8	1.63			
% C4H10 normal	0.42			
% C4H10 iso	0.33			
% C5H12 normal	0.10			
% C5H12 iso	0.11			
% C6H14	0.05			
% C7H16	0.03			
% C8H18	0.01			
% CO2	4.79		0.70	0.22
% CO				0.45
% H2S	0.01			0.18
% H2				1.82
% O2	0.02			0.35
% N2	0.58	0.80	0.50	3.40
% Moisture	0.03			

COMPARATIVE ANALYSIS OF FUELS

FUEL	GROSS CV MJ/kg	NET CV MJ/kg	Typical Air, %	API	Btu/Lb	%C	%H	%S	%O	%N	%ASH	%H20
Coal/Water Slurry	29.9	27.6	15-20%		13330	84.51	10.28	4.08	0.28	0.70	0.14	29.00
LPG Butane	49.4	45.6										
LPG Propane	50.2	46.2										
LPG	49.3	45.5	3-15%		21180	82.43	17.57				0.00	
Gasolene	45.9	43.0		61.0	20500	84.50	15.40				0.00	
Kerosene/Avturbo	46.5	43.5		47.1	19800	84.70	15.30				0.00	
Diesel	45.7	42.9		36.0	19650	85.50	13.00	0.80			0.70	
Gas Oil	45.6	42.8										
Light Fuel Oil	43.5	41.1	3-15%	27.2		85.60	12.00	0.40	0.60	0.50	0.90	
Medium Fuel Oil	43.1	40.8	3-15%	15.0	18600							
Heavy Fuel Oil	42.9	40.5	3-15%	16.7		84.70	12.40	1.10			1.80	
Naphtha	46.8	43.0		60.0	20620							
Avgas	48.7			64.6	20950							
Methanol	22.7	19.9		46.3	6600	37.48	12.58		49.94		0.00	
Ethanol	30.2	27.2		46.7	12800	52.14	13.13		34.73		0.00	
Coconut Oil	36.6	34.3		21.5	15748	76.28	10.87		12.82		0.00	
Coal 1 anthracite	29.7	28.9	15-20%		12750	79.80	2.50	0.60	7.30	0.80	9.00	6.00
Coal 2 general purpose	25.3	24.8	25-35%		11630	65.80	5.70	0.50	18.10	1.10	8.80	7.90
Coal 3 low grade	15.6	14.9	25-40%		8710	49.70	6.40	0.40	31.90	0.80	10.80	21.90
Coke Breeze	28.6	28.4	3-15%		11670	86.30	0.32	0.65	0.54	0.32	11.87	7.30
Lignite	21.5	20.2			7050	41.30	6.70	0.40	42.60	0.70	8.30	34.00
Wood Waste	15.8	14.4	20-25%		3591	48.99	6.20		44.25	0.06	0.50	30.00
Bagasse	9.3	8.1	20-25%		4000	48.75	5.83	0.00	41.67	0.21	3.54	52.00
Municipal Solid Waste			80-100%									
Refuse Derived Fuels RDF			40-60%									
Rice Hull	14.0				6000							
Coconut Shell	20.1				8630							
Coconut Husk	17.2				7400							
Peat	15.9	14.5										
Natural Gases:			3-15%									
North Sea (UK)	54.3	47.6			23345							
Arzew	54.5	49.3			23431							
Groningen	42.4	38.3			18229							
SNG (CRG + 2 stage Methanation)	52.5	47.3			22571							

ESTIMATED EMISSIONS FROM ELECTRIC POWER GENERATION (tons/GWh)

Emissions from Electric Power Plants (tons/GWh)					
Fuel	**SO2**	**NOX**	**PM10**	**CO2**	**VOCs**
Easter Coal	1.74	2.90	0.10	1,000	0.06
Western Coal	0.81	2.20	0.06	1,039	0.09
Natural Gas	0.003	0.57	0.02	640	0.05
Oil	0.51	0.63	0.02	840	0.03
Biomass	0.06	1.25	0.11	0	0.61
Wind					
Geothermal					
Hydro					
Solar					
Nuclear					

SOURCE: Renewable Energy Annual 1995, US EIA, p. 9, Table H1.

BASIC ENGINEERING UNITS OF MEASURE

Length (meter, m; kilometer, km)

Area (square meter, m^2; hectare, ha)

Volume (cubic meter, m^3; liter, L)

Force (Newton, N)

Temperature (degrees Celsius, deg C; degrees Kelvin, deg K)

Energy as heat (Joule, J) or work (kilo-Watt-hour, kWh)

Frequency (Hertz, Hz, 1/s)

Electric charge (Coulomb)

Electric current (Amperes, Coulomb/s, A)

Electric voltage (Volts, V)

Apparent Power (Volt-amperes, kVA)

Power (Watt, W) or work/heat flow rate (kilo-Joule/second, kJ/s or kW)

Calorific Value as higher heating value or lower heating value (kJ/kg)

Density (kg/m^3, kg/L) or specific volume (m^3/kg, L/kg)

Pressure (atmosphere, atm or bar) or force per unit area (N/m^2)

Dynamic Viscosity (Poise, P) and Kinematic Viscosity (Stokes, S)

Emissions (milli-gram/normal cubic meter, mg/Nm^3; kg CO_2/kWh)

Noise level (decibel, dB)