Heating Value (energy density) comparison

- [kJ/kg]

Firewood	16,000	
Coal	30,000	
Natural gas	50,000	
LPG	50,000	
Gasoline	45,000	
Methane (CH4)	50,000	
Hydrogen (H2)	120,000	
Uranium (Natural)	500,000,000	[500 GJ]
Uranium (Enriched to 3.5%)	3,900,000,000	[4 TJ]

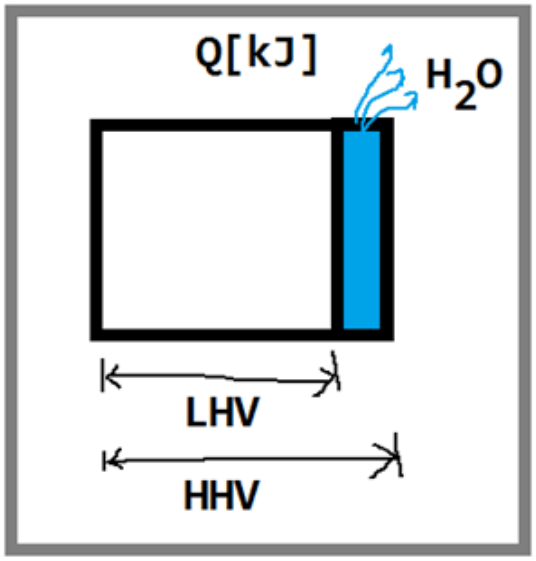
Heating Value Types: LHV and HHV

- Gross HV = High HV (HHV)
- Net HV = Low HV (LHV)

- Background (in fuel burning)
  - Hydrocarbon (CH4, C3H3, C4H10) produces heat and water vapor
  - Water vapor is released during burning, which is not extractable heat ("latent heat")

Heating Value Types: LHV and HHV

- HHV:
  - HV with latent heat included
- LHV:
  - HV with latent heat excluded
- HHV > LHV



Higher Heating Value (HHV) and Lower Heating Value (LHV) for Various Fuels[a]

	Higher Heating Value HHV		Lower Heating Value LHV		
Fuel	Btu/lbm	kJ/kg	Btu/lbm	kJ/kg	LHV/HHV
Methane	23,875	55,533	21,495	49,997	0.9003
Propane	21,669	50,402	19,937	46,373	0.9201
Natural gas	22,500	52,335	20,273	47,153	0.9010
Gasoline	19,657	45,722	18,434	42,877	0.9378
No. 4 oil	18,890	43,938	17,804	41,412	0.9425

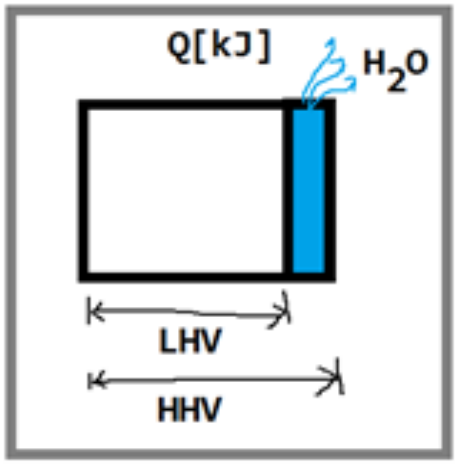
[a]The gases are based on dry, 60°F, 30-in. Hg conditions. Natural gas is a representative value.

Source: Based on Babcock and Wilcox (1992) and Petchers (2002).

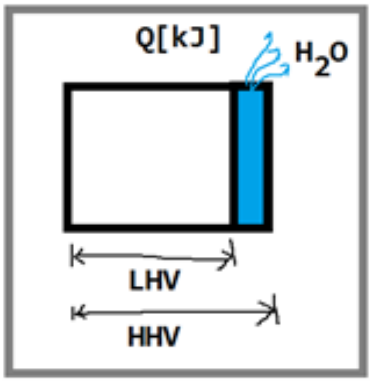
lbm: pound-mass

HHV and LHV efficiency

- HHV: Appears to be Lower Efficiency
- LHV: Appears to be higher efficiency
- Fuel Rate [kg/kWh] is the same



HHV and LHV efficiency Relationship

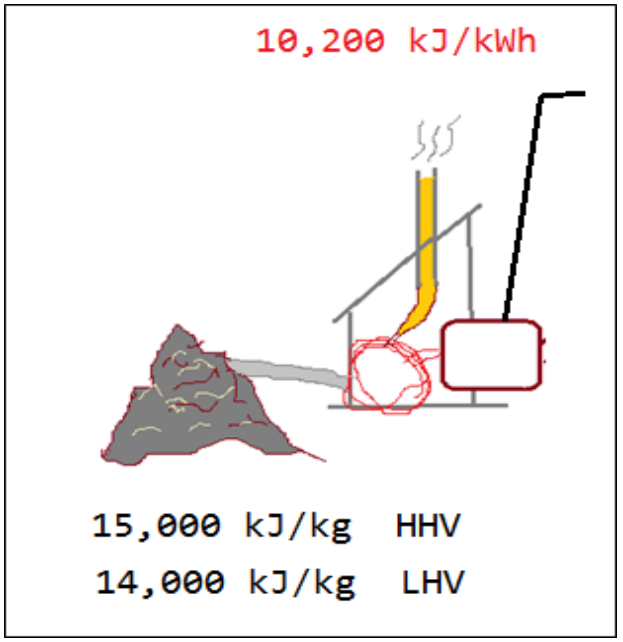


HHV vs LHV - Example 1

- A micro-turbine has a natural gas input of 14,500 kJ in LHV per kWh electricity generation output. Find (a) LHV efficiency and (b) HHV efficiency if LHV/HHV = 0.901.

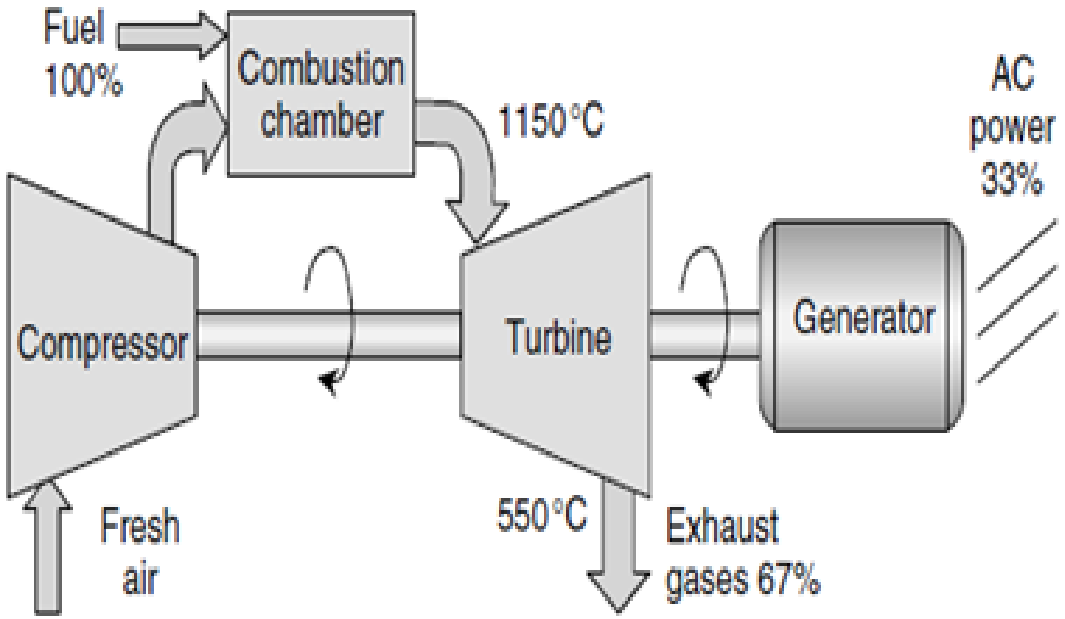
HHV vs LHV - Example 2

- On an HHV basis, 600-MW coal-fired power plant has a heat rate of 10, 200 kJ/kWh. The particular coal has an LHV of 14,000 kJ/kg and HHV of 15,000 kJ/kg.
- (a) find HHV efficiency of the plant
- (b) find the LHV efficiency of the plant
- (c) at what rate the coal has to be supplied [kg/hour] ?



Combustion Gas Turbines

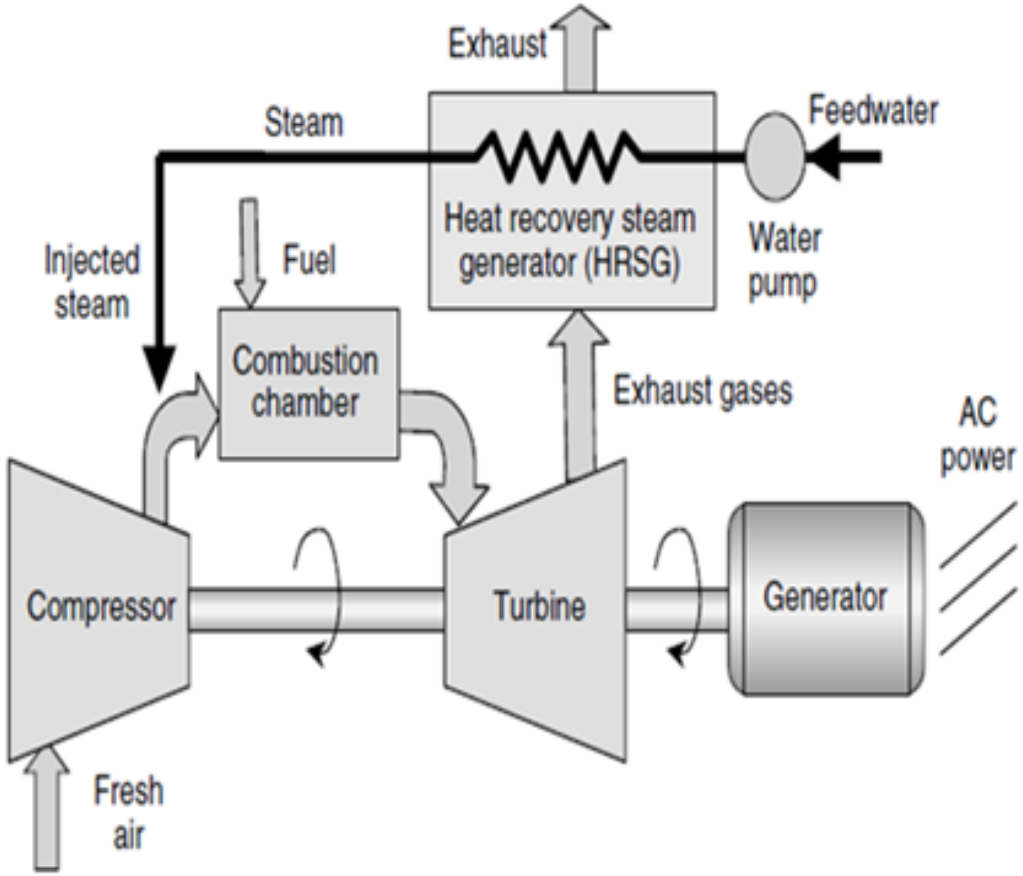
- **Basic Gas Turbine**
  - Fuel: Natural Gas
  - Compressor and Turbine shares a connecting shaft
  - ½ the rotational energy created by the spinning turbine is used to power the compressor



Combustion Gas Turbines

Steam-Injected Gas Turbine (STIG)

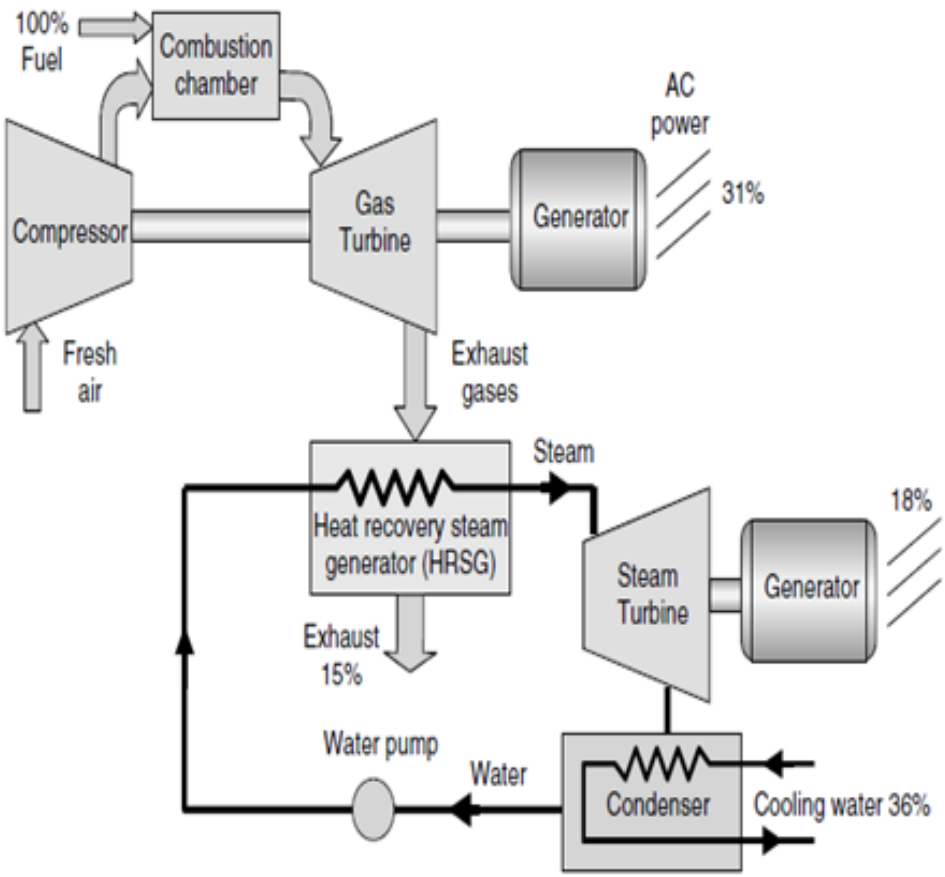
- Increased Efficiency by a heat exchanger
- Heat Recovery Steam Generation (HRSG)
  - Injected Steam
  - Effect of fuel reduction
- HRSG reduces the combustion temperature
  - Reduced NOx emission
- Efficiency 45%
- More Expensive



Combined-Cycle Power Plant

Combined-Cycle Gas Turbine

- Gas turbine waste heat can be used to power a second-stage steam turbine → Coupling a gas turbine and steam turbine → Combined Cycle Plant
- 49% Efficiency



Combined-Cycle Power Plant

- **Cogeneration**:
  - Electricity + Thermal Energy (Steam Turbine Electricity Generation + Heating)