Third Workshop on Marine Black Carbon Emissions: Measuring and Controlling BC from Marine Engines

September 7 and 8, 2016
Vancouver, BC

Team results from UC-Riverside; National Research Council of Canada; and Environment and Climate Change Canada

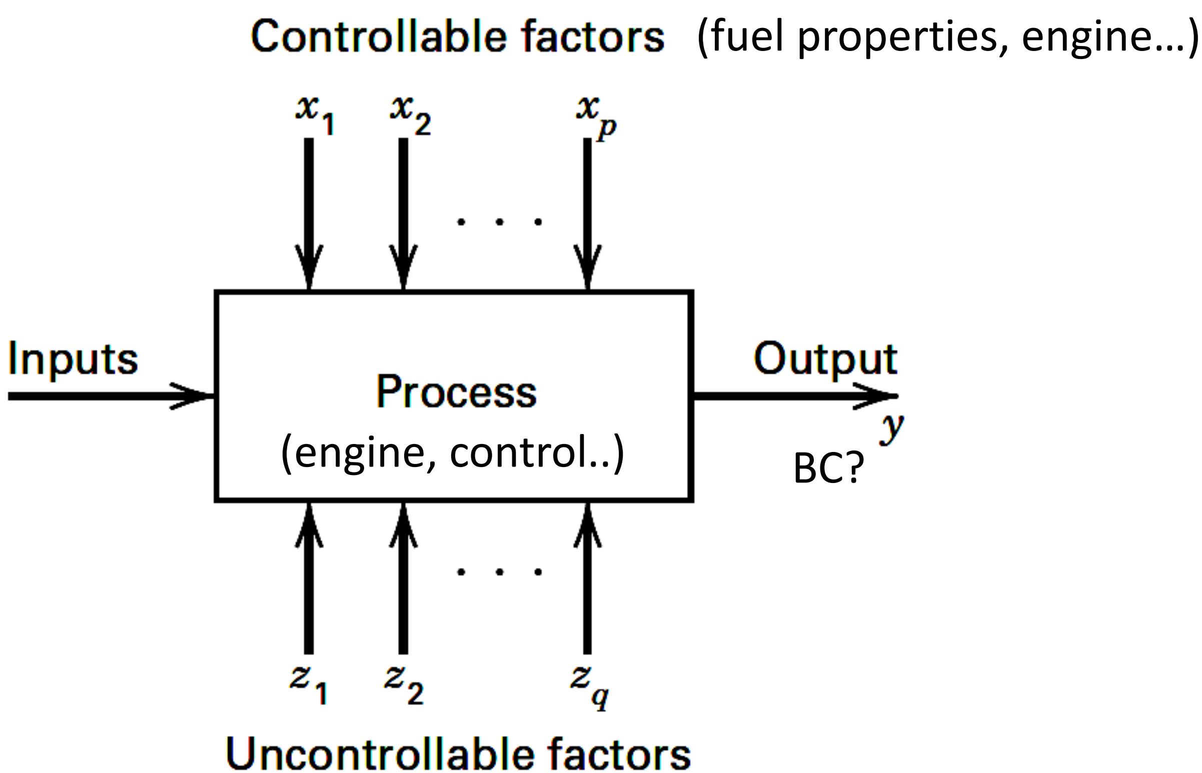
Funding from ICCT and MARAD

Discussion Topics

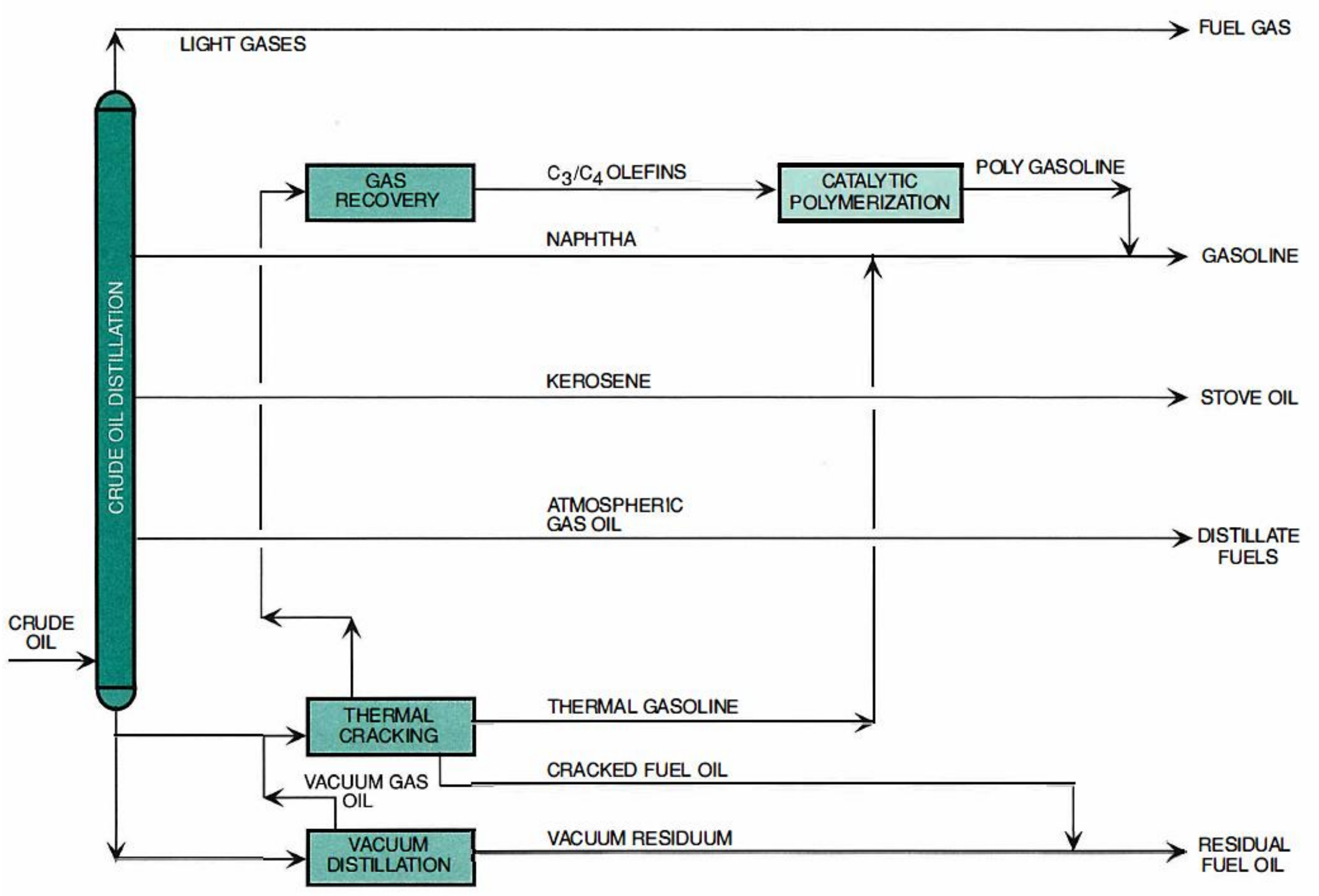
- **Session 2: Marine Fuels and BC**
  - Fuels manufacture
  - Engine selection
  - Results
  - Pathways to predicting Black Carbon (BC) emissions.

Can you predict BC from fuel properties?

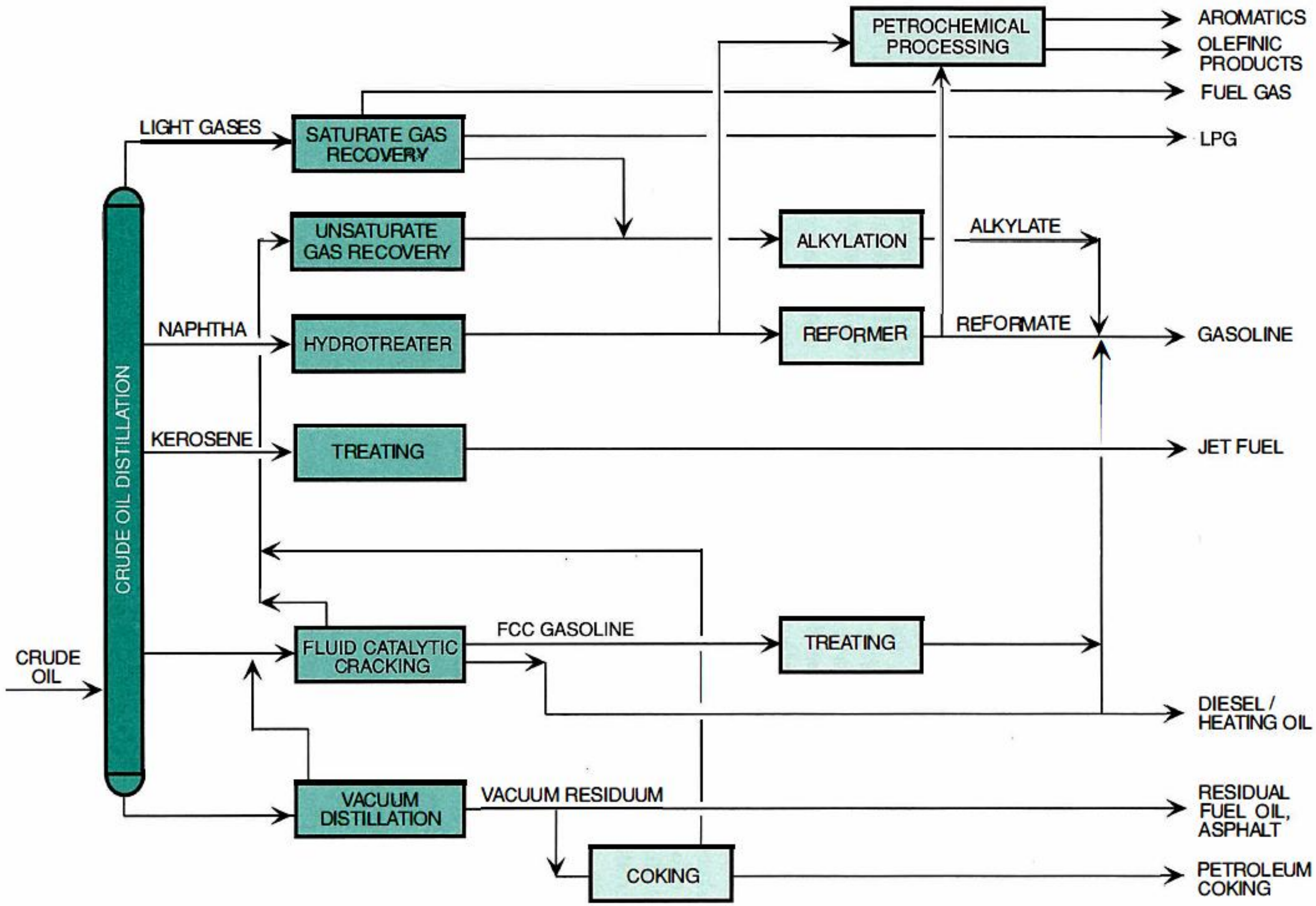
General model of a process or system



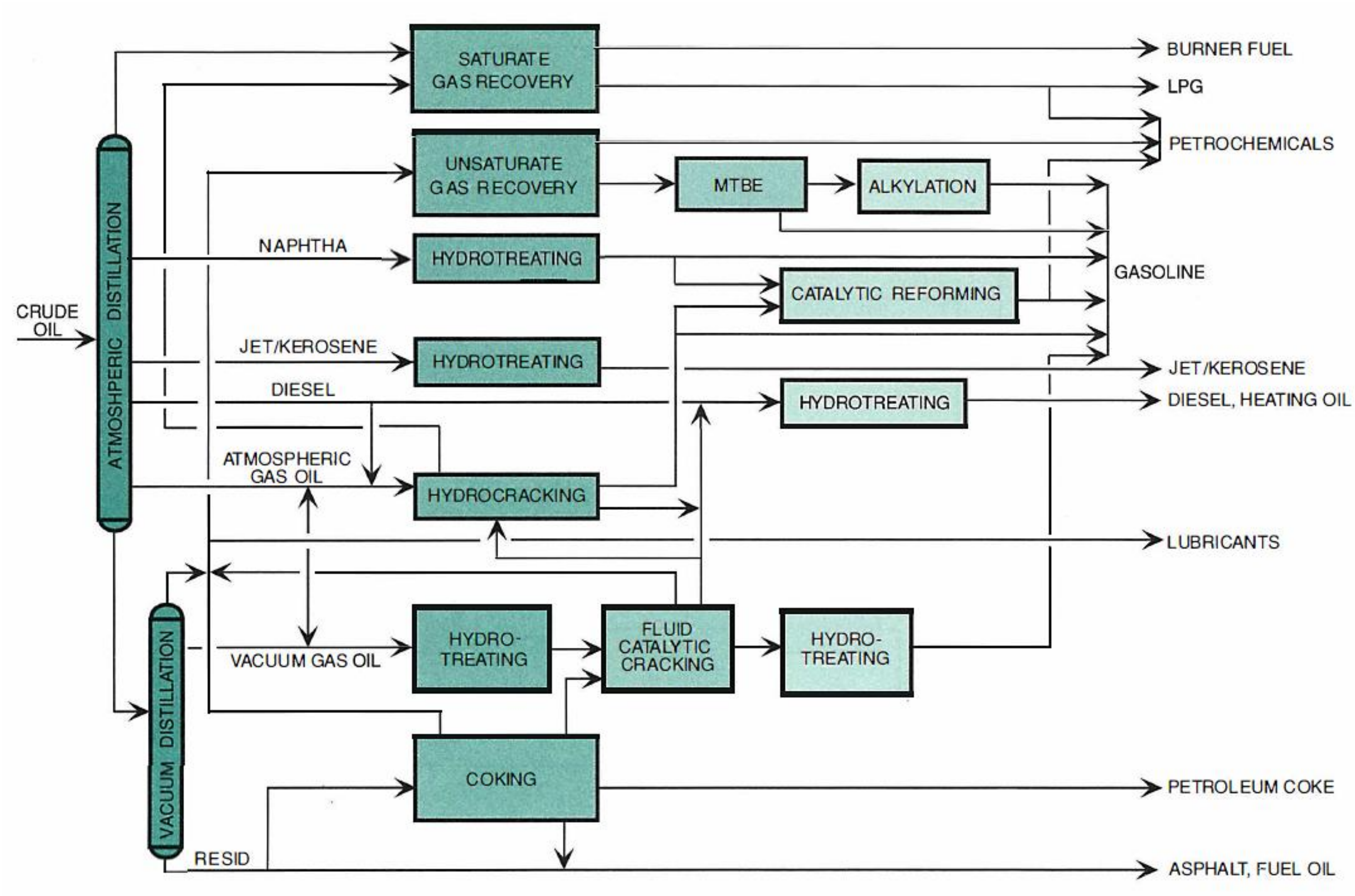
Refinery in 1930



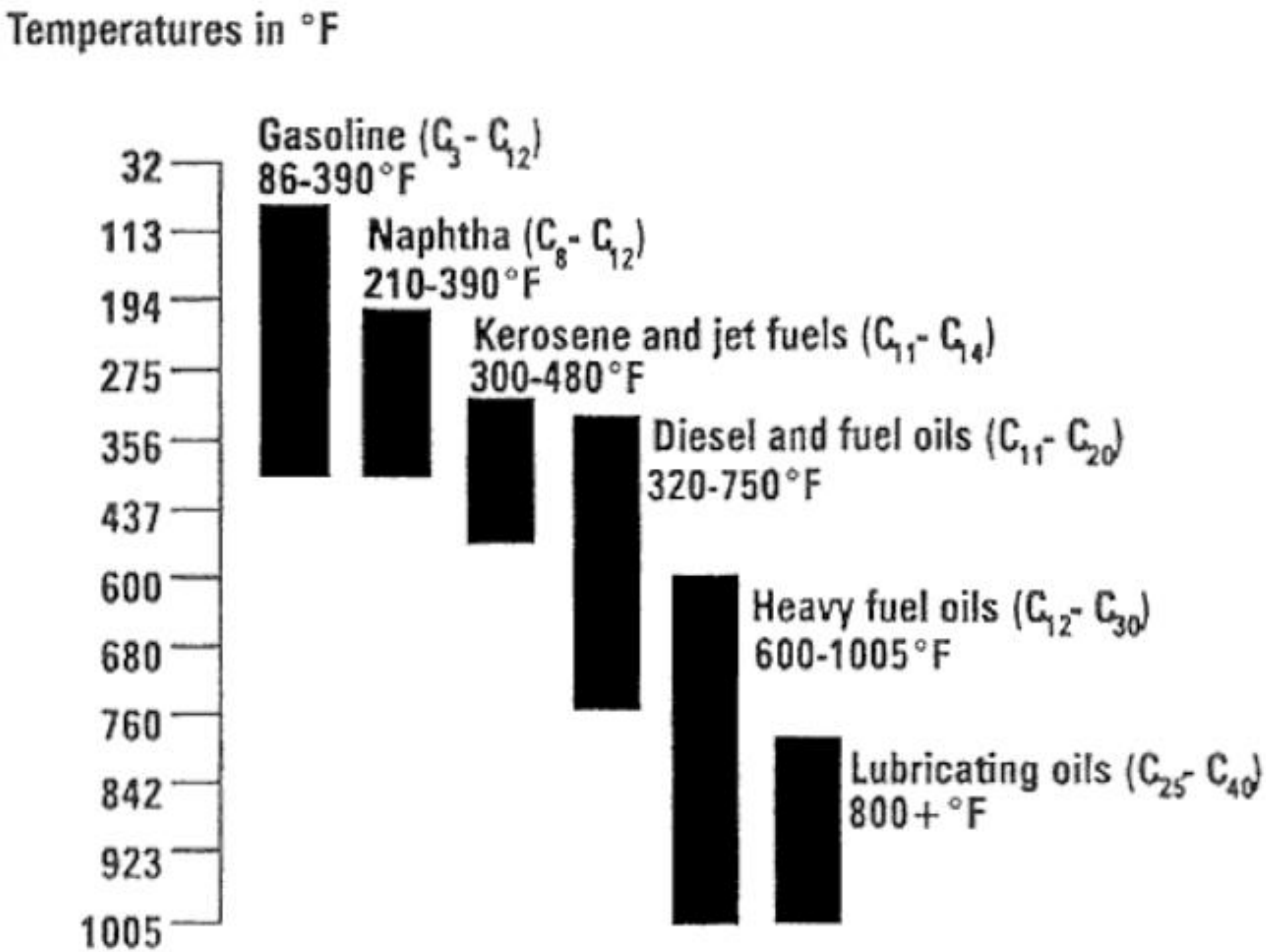
Refinery in 1950



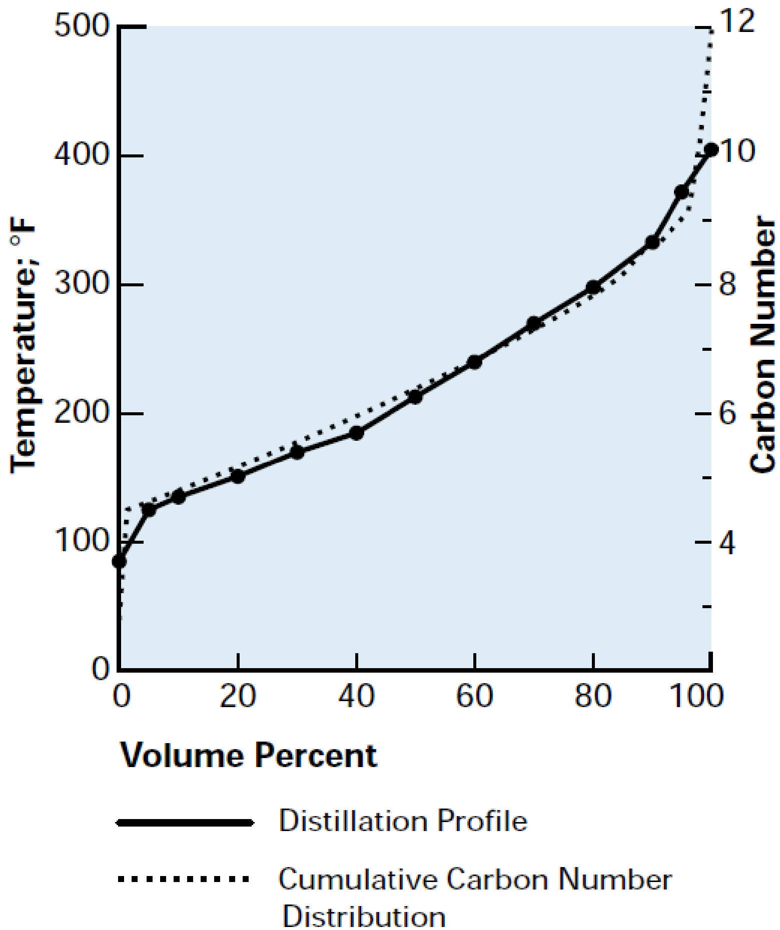
Modern Refinery Schematic



Boiling Range & Carbon Number for Common Petroleum Products



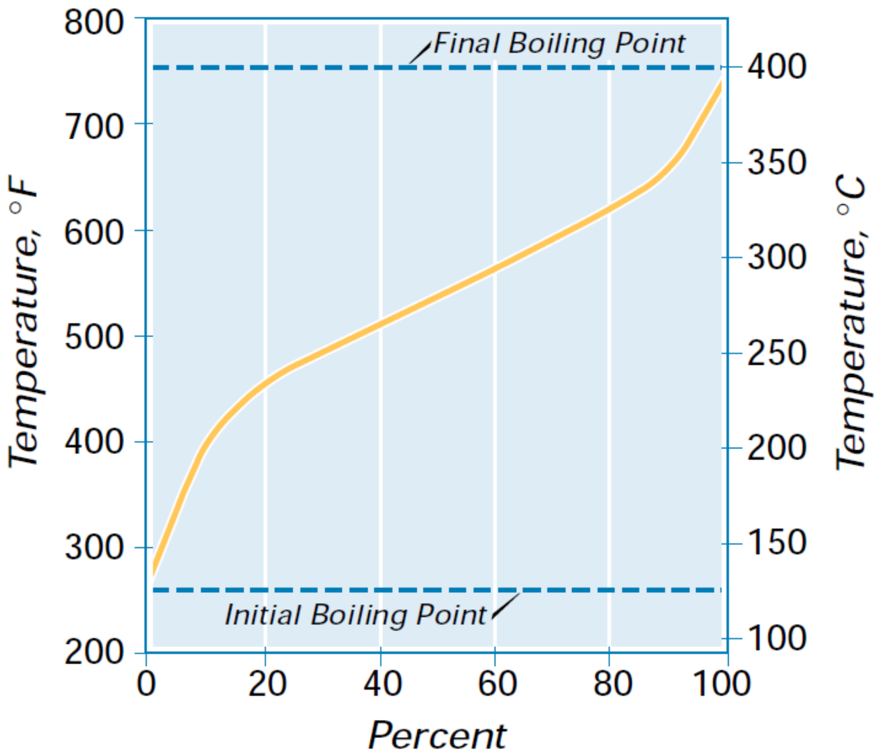
Motor Gasoline Properties

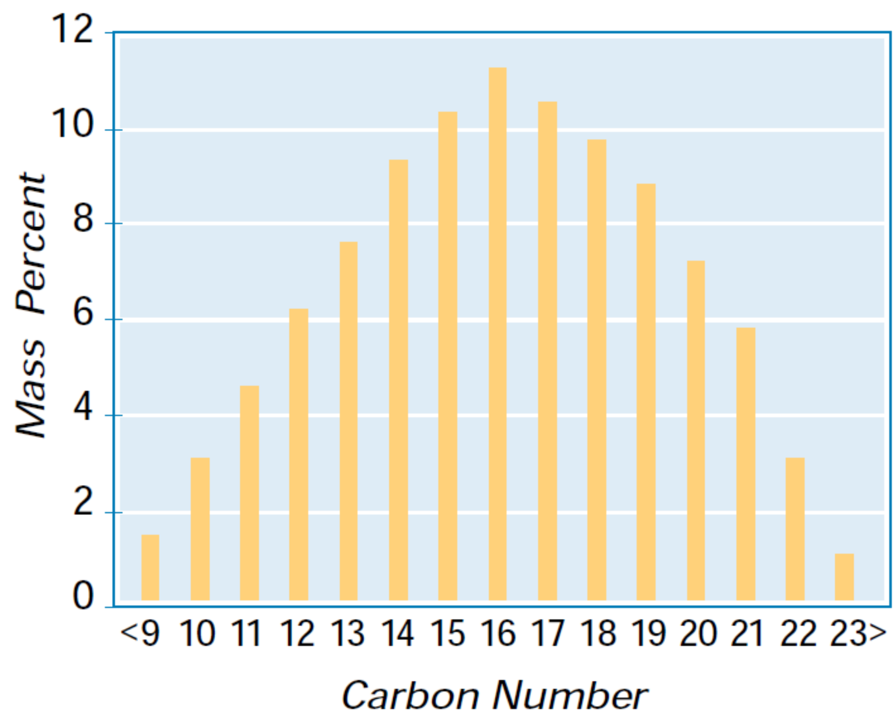


Compound	n-Hexane	1-Hexene
Formula	C_6H_{14}	C_6H_{12}
Structure	$CH_3(CH_2)_4CH_3$	$CH_2{=}CH(CH_2)_3CH_3$
RON	25	76
Compound	2,2,4- Trimethyl-pentane (Isooctane)	2,4,4-Trimethyl-1-pentene (Isooctene)
Formula	C_8H_{18}	C_8H_{16}
Structure	$CH_3C(CH_3)_2CH_2CH(CH_3)CH_3$	$CH_2{=}C(CH_3)CH_2C(CH_3)_2CH_3$
RON	100	106

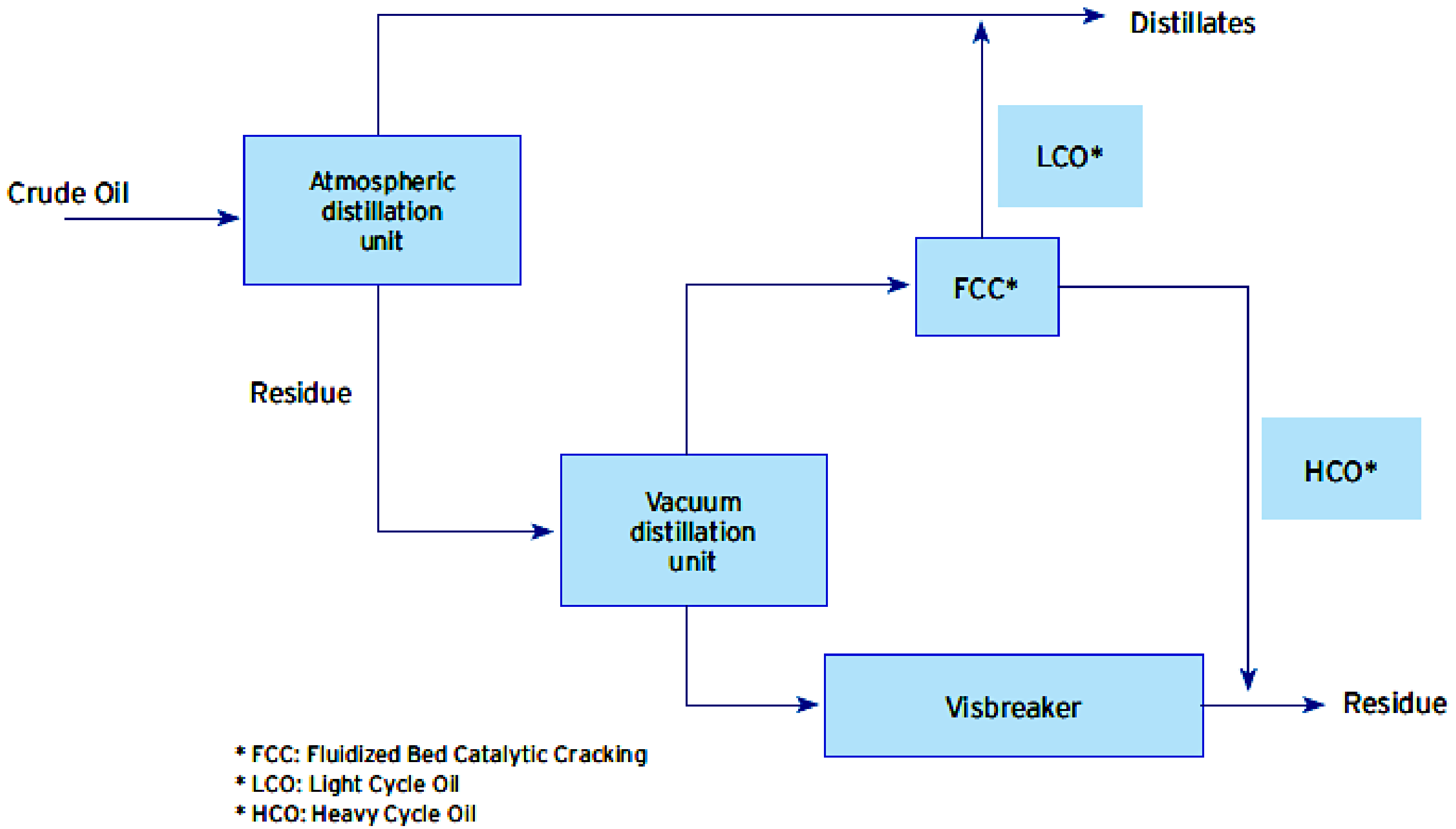
Octane depends on molecular structure

Diesel Fuel Properties





Manufacturing IFO-380

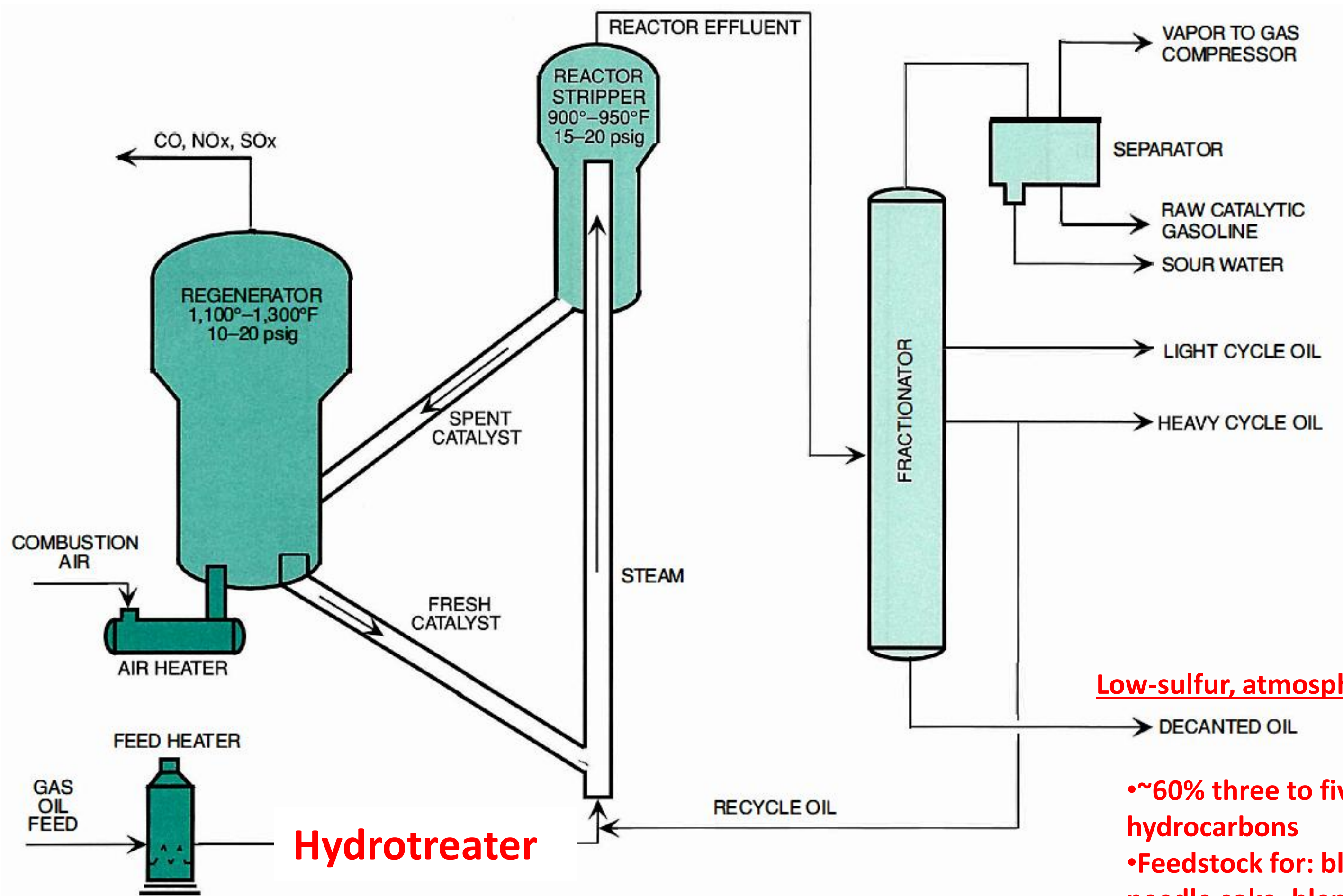


•IFO-380 is manufactured by blending vacuum residue with HCO and LC(G)O for fine tuning. The aromaticity of these streams adds stability for the fuel blend.

•For IFO blends < 380; add marine diesel, SR gasoil, LC(G)O to meet specs.

•All fuels meet ISO 8217 - Specifications of marine fuels

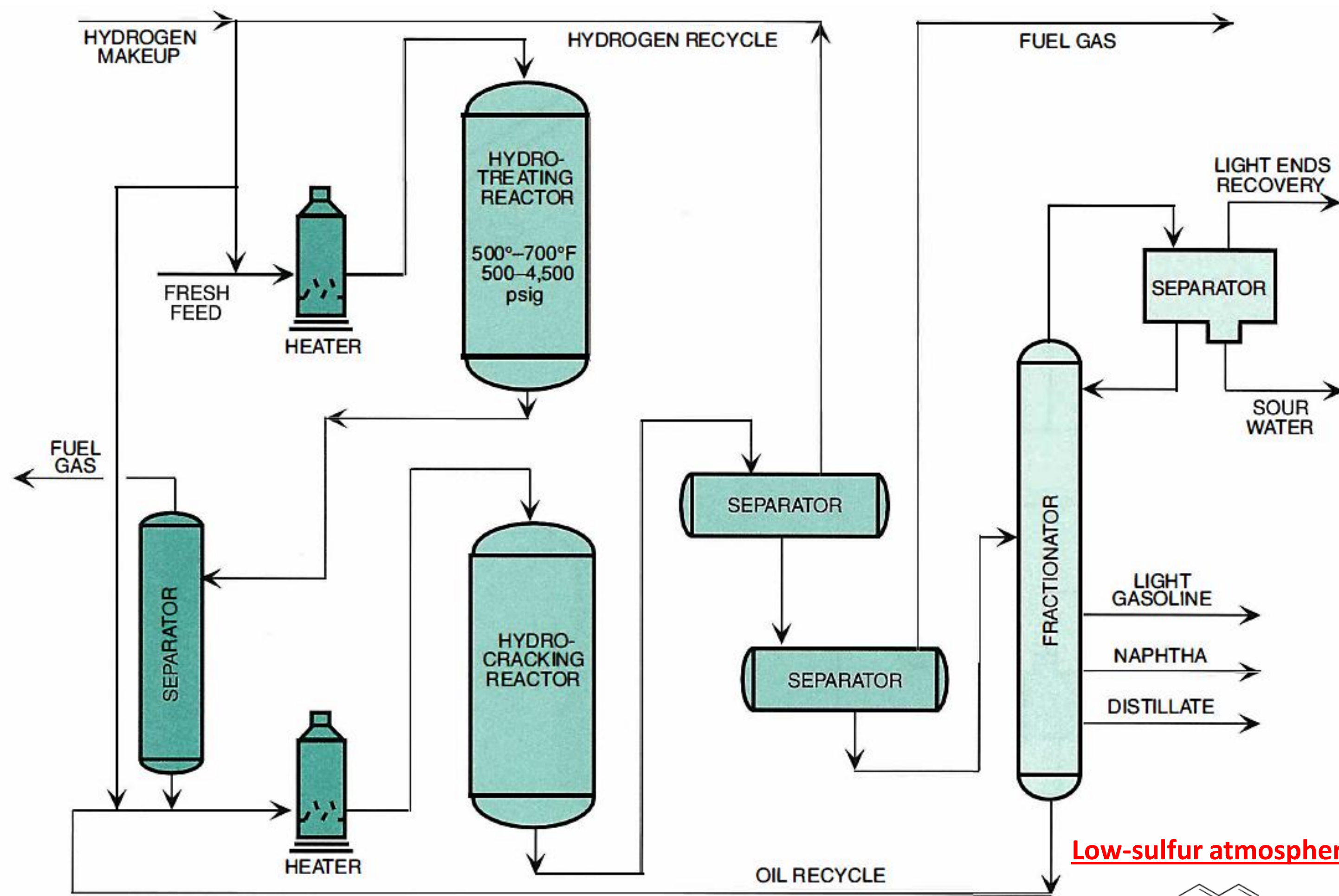
Typical Fluid Catalytic Cracker



<u>Low-sulfur, atmospheric residual fuel</u>

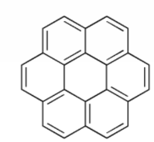
- ~60% three to five ring aromatic hydrocarbons
- Feedstock for: black carbon, needle coke, blending FOs

Typical Hydrocracker Unit

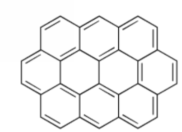


Low-sulfur atmospheric residual fuel

Trace



Coronene

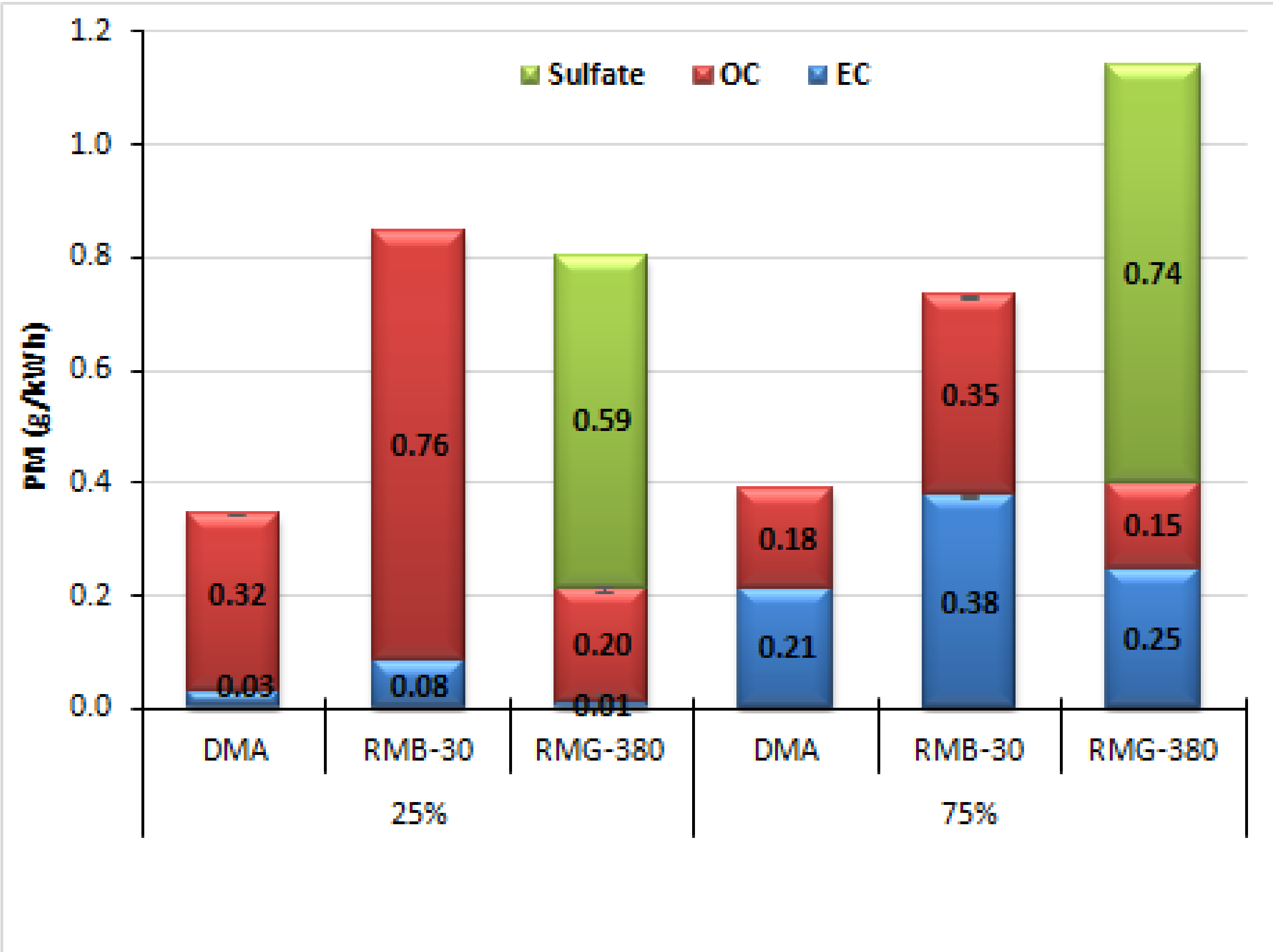


Ovalene

Selected Engines Properties

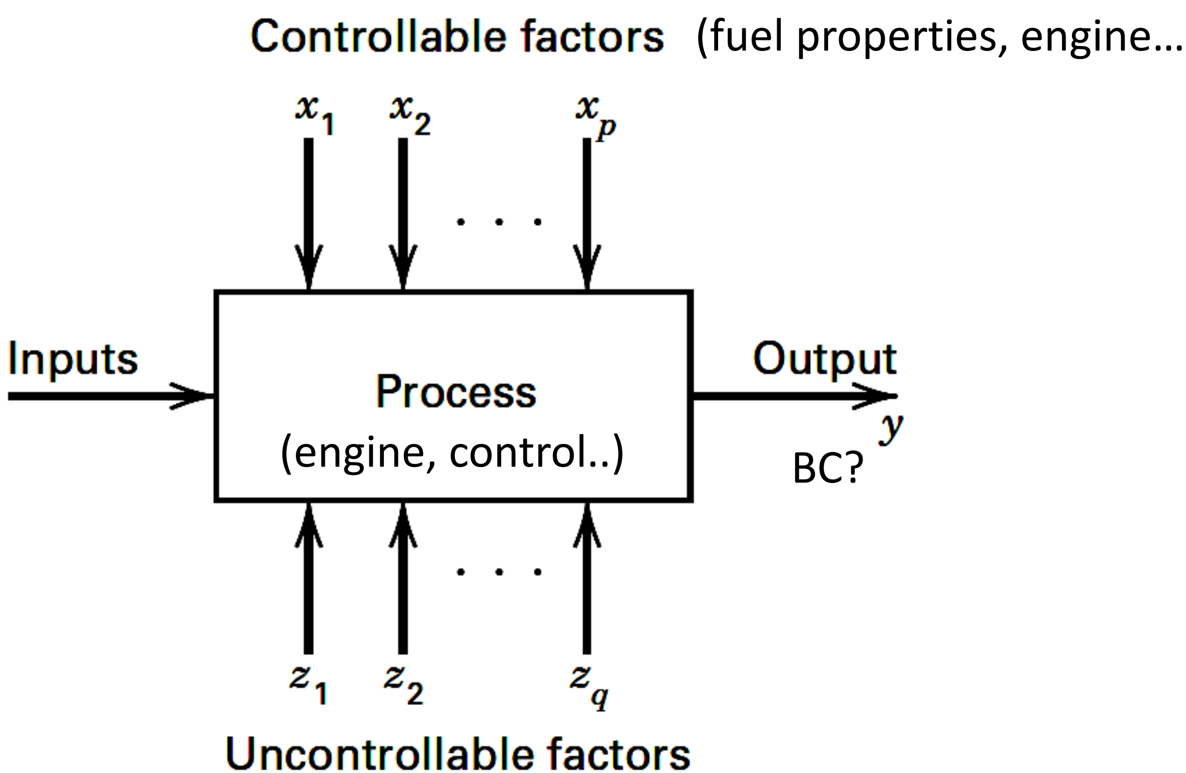
Manufacturer	Detroit Diesel Corp	MAN	Hyundai/MAN
Model	6-71N	6L48/60	11K98ME7
2 or 4-stroke	2-stroke	4-stroke	2-stroke
Number of cylinders	6	6	11
Engine speed, RPM	2,300	512	97
Brake horsepower, kW	187	6,300	68,530
Tier	0	1	1

PM Emissions Depend on Fuel & Load



Can you predict BC from fuel properties?

General model of a process or system

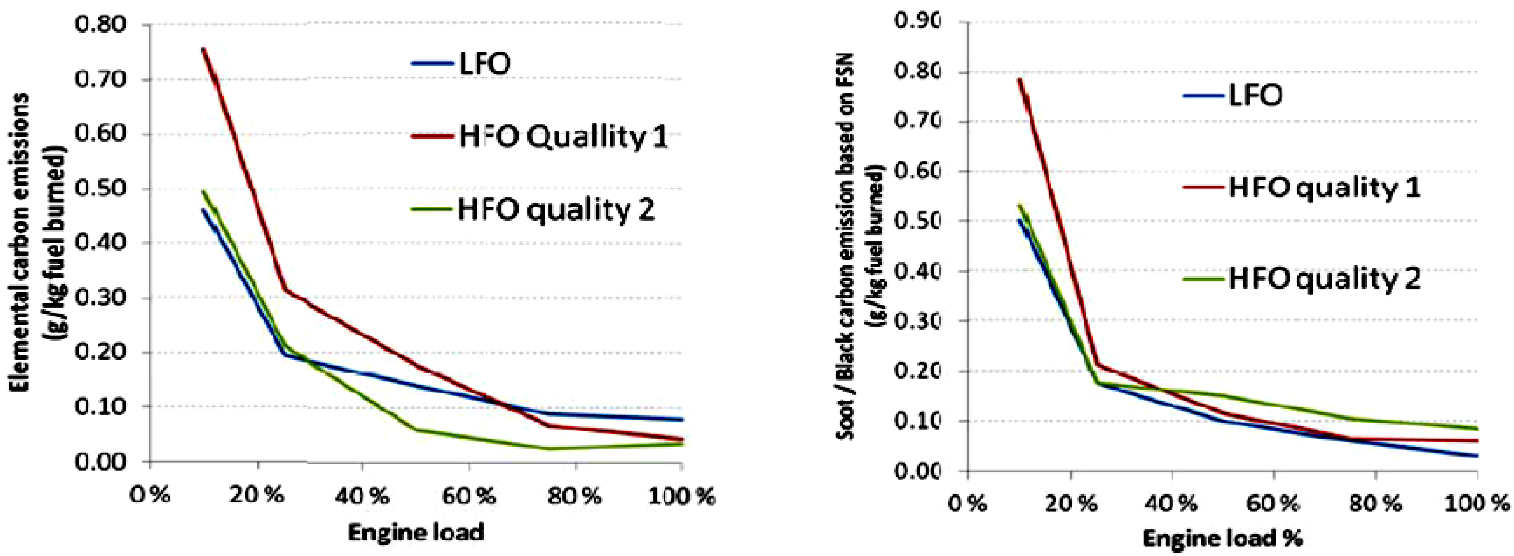


BC Not Related to Fuel Properties

Selected Fuel Properties

	Unit	LFO	HFO quality 1	HFO quality 2
Viscosity @ 50°C	mm²/s	@40°C 3.4	167.2	498.0
Viscosity @ 80°C	mm²/s	1.699	39.5	87.49
Sulphur	% m/m	<0.05	0.89	2.42
Ash	% m/m	<0.01	0.02	0.07
Vanadium	mg/kg	<1	39	299

Wärtsilä results on 4-stroke engine



Reference: CIMAC; *Background on Black Carbon Emissions from Large Marine Engines*, Jan 2012

Selected Fuel Properties

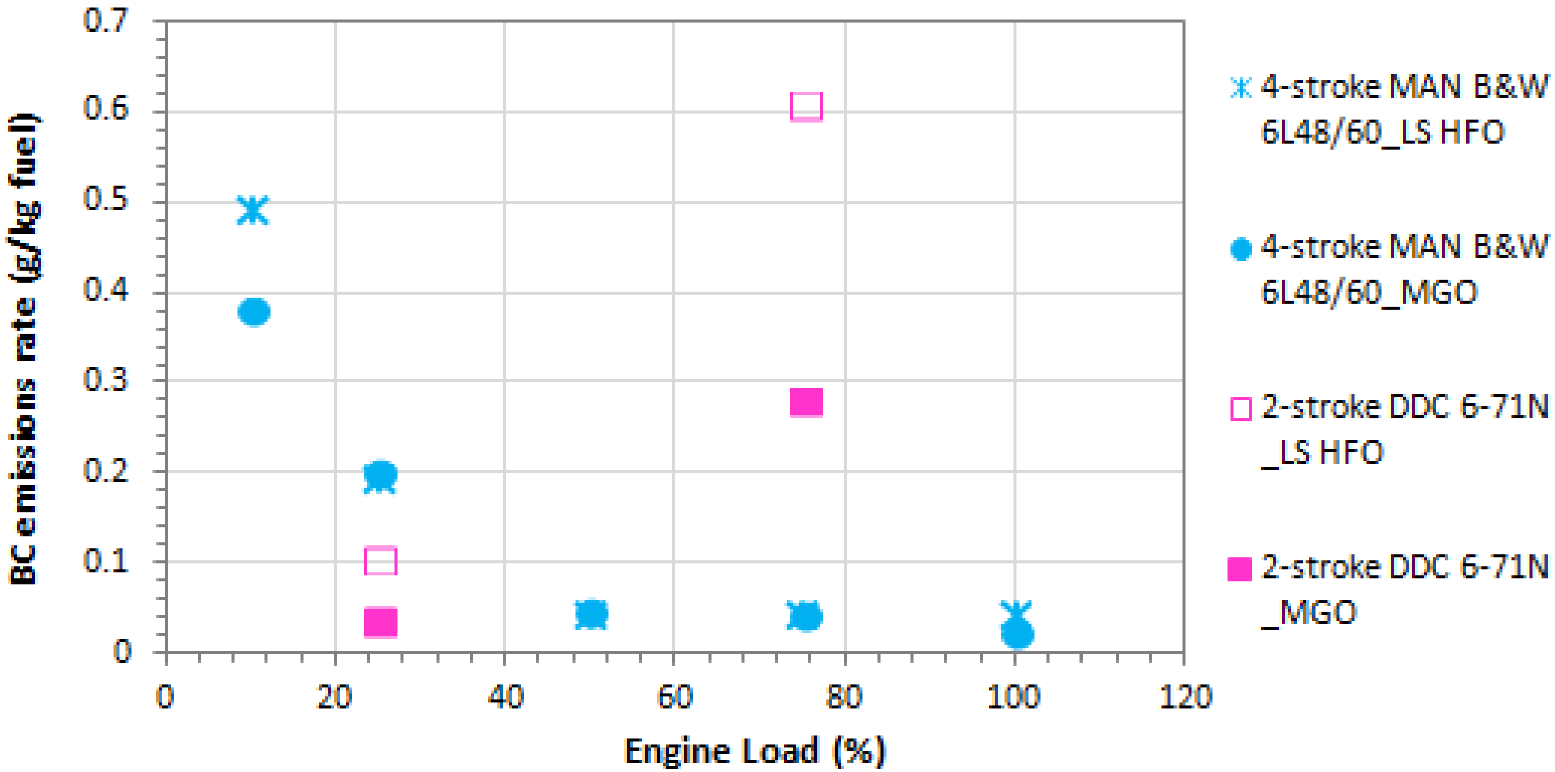
Fuel	DMA	RMB-30	RMG-380
Sulfur wt% (ppm)	13	13.2	31,849
Density @ 15˚C (kg/L)	0.8309	0.8586	0.9826
Viscosity @ 40˚C (cSt)	2.696		
Viscosity @ 50˚C (cSt)		13.73	358.9
Micro Carbon Residue (%m/m)	< 0.1	< 0.1	12.84
CCAI_calculated		769	845

Calculated Carbon Aromaticity Index (CCAI) can be calculated:

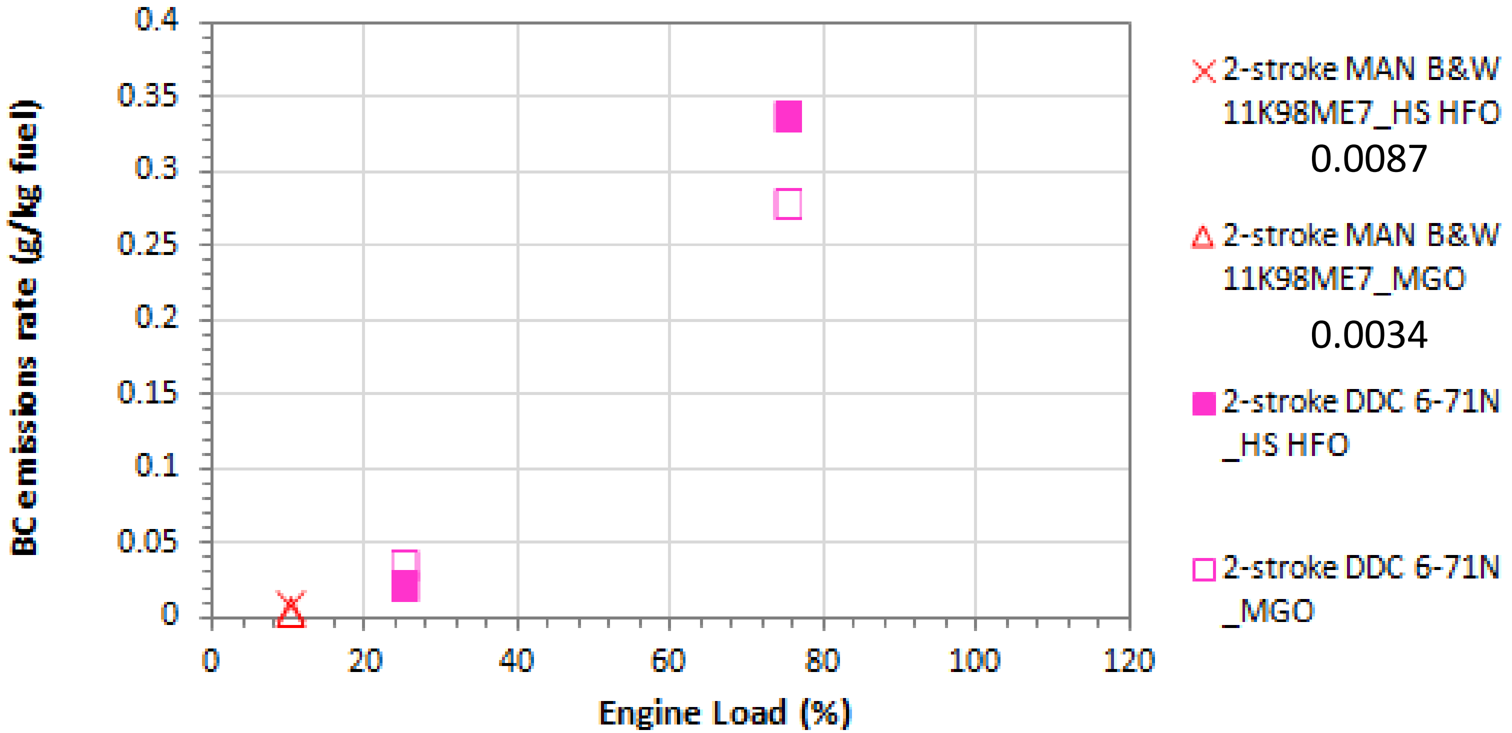
$$CCAI = D - 81 - 141 Log[Log(Vk + 0.85)] - 483 Log\left[\frac{T + 273}{323}\right]$$

Where: D = density at 15°C, kg/m³
Vk = kinematic viscosity (mm²/s) at temperature T°C

Compare Distillate & Low-S HFO

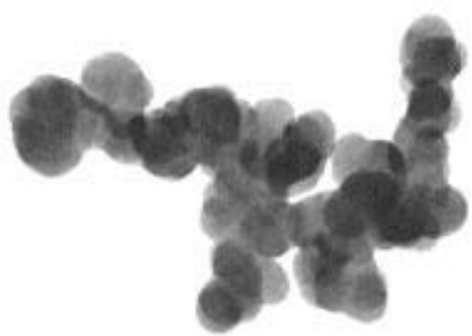


Compare Distillate & High-S HFO



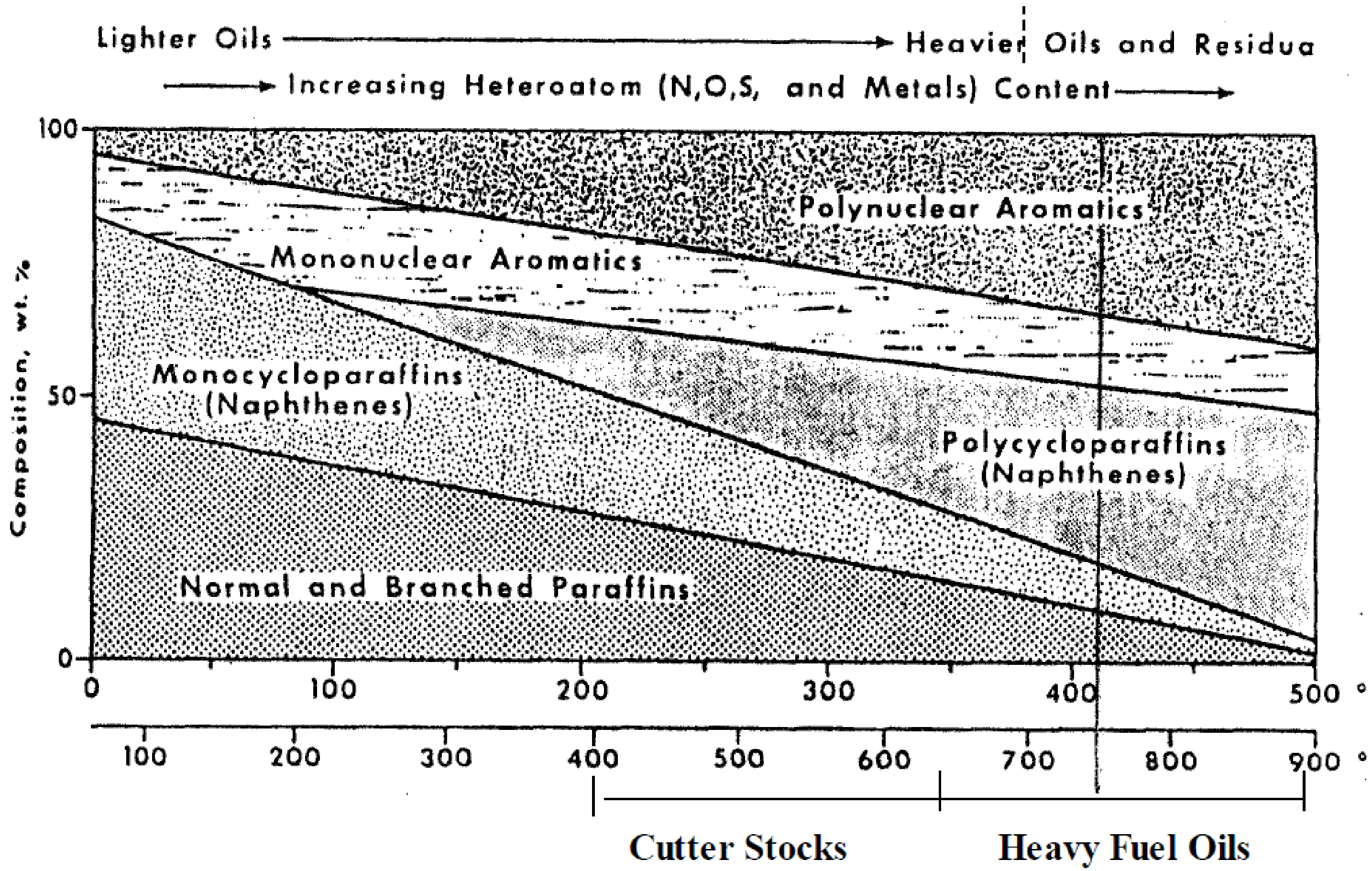
Discussion: Pathways to BC

- Furnace oil process
  - Accounts for 90% of production.
  - Heat hydrocarbons to between 1300°-1500°C with a limited supply of combustion air.
  - Collect unburned carbon; an extremely fine, black fluffy particle, 10 to 500 nanometers (nm) in diameter.



Discussion: Pathways to BC

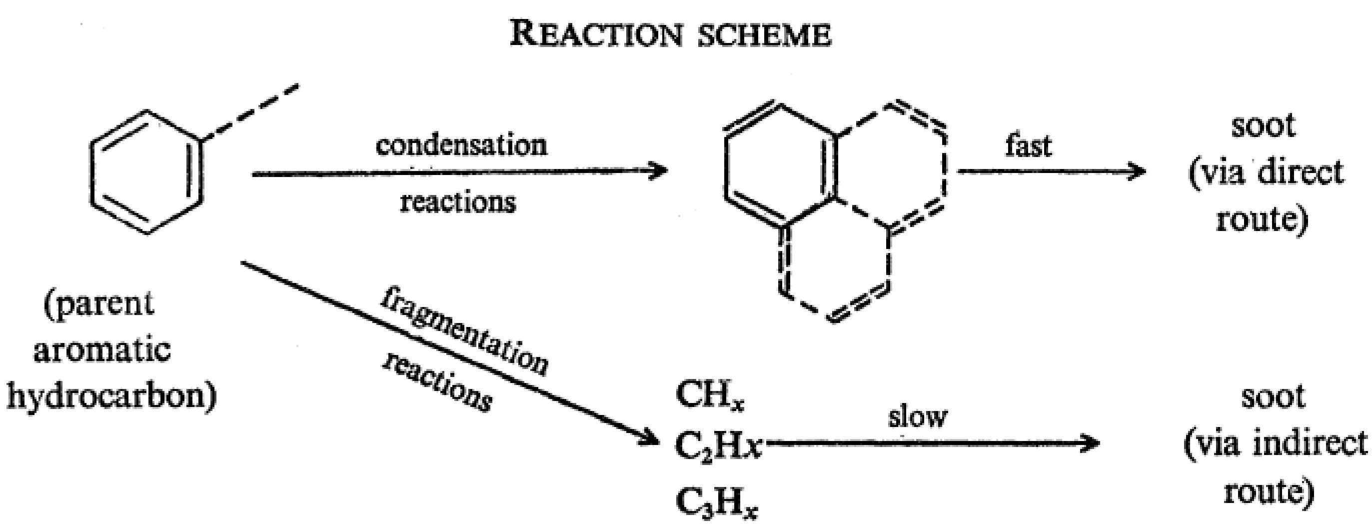
- Composition of marine fuels



Reference: Speight, J. G. *Petroleum Chemistry and Refining*. Applied Energy Technology Series. Taylor and Francis, Washington, D.C. (1998)

Discussion: Pathways to BC

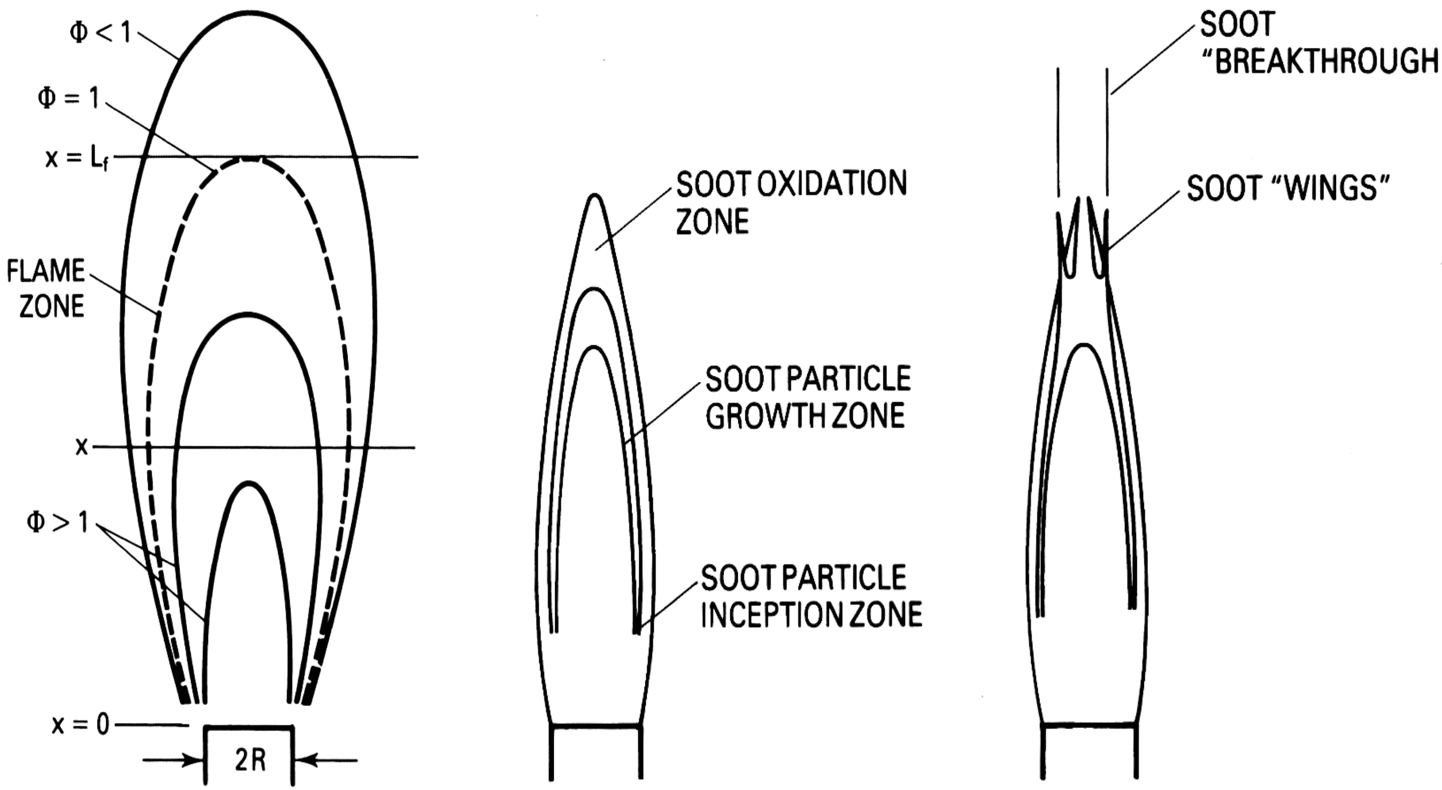
- Research on combustion kinetics—chemistry



Reference: Graham et al; *Proceedings of the Royal Society of London. Series A, Mathematical and PhysicalSciences*, Vol. 344, No. 1637 (Jun. 24, 1975),

Discussion: Pathways to BC

- Diesel combustion process



Reference: Turns, *An Introduction to Combustion,* McGraw-Hill, 1996

Summary

- Predicting BC emission rates from simple fuel properties is not likely.
- BC emission rates for large engines differ from values from small engines. Real world data needed.
- Prediction of BC emissions will likely require a deeper analysis of the chemistry of the fuels, especially aromatics, and the associated combustion processes.