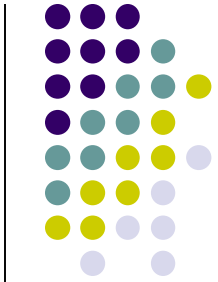
Principal FUELs for energy conversion

The energy resources available to fulfill the world demand:



1. Biomass fuels (crops, wood, municipal solid waste)
2. Fossil (oil, coal, natural gas)
3. Nuclear fuels
4. Geothermal
5. Solar radiation
6. Hydropower
7. Wind
8. Ocean

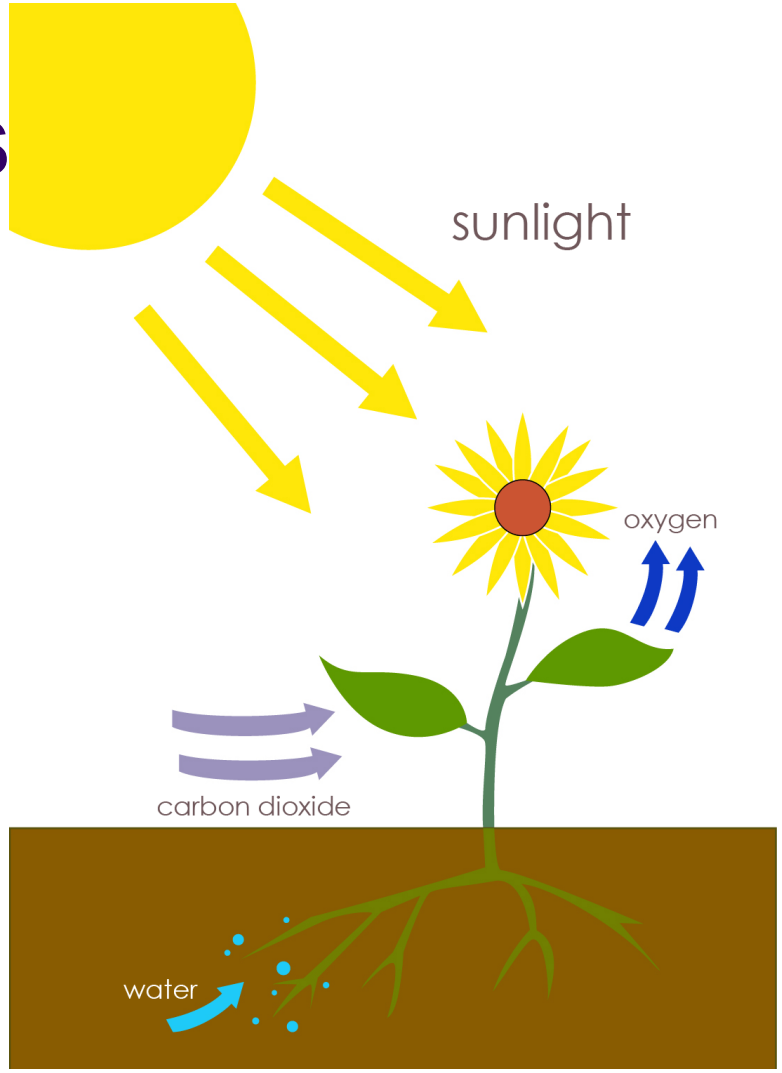
Importance of fossil fuels:

- Out of all the energy resources, fossil fuels have been used the most (88% of total consumption) ***because*** of their extremely high energy densities and simplicity of conversion and use.

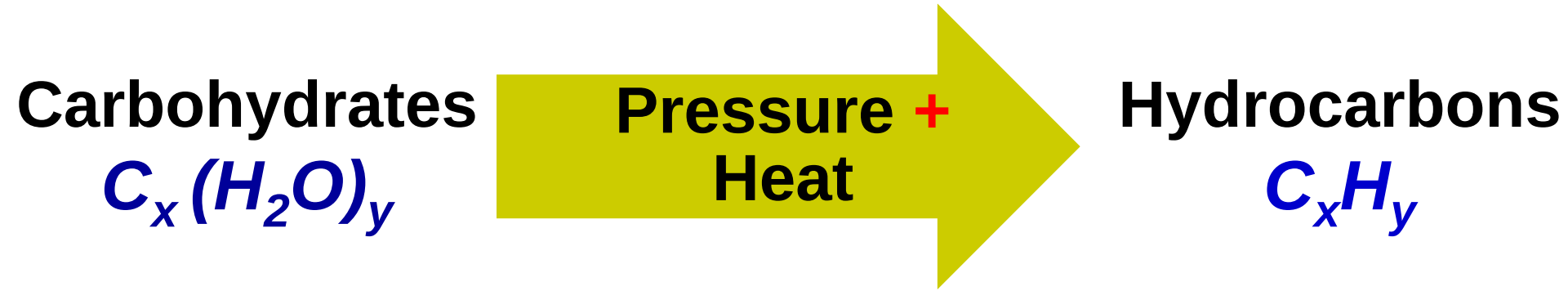
What is a fossil fuel?

- ***Fossil fuel:*** These are produced from fossilization of carbohydrate compounds. ***Example***: Coal, Oils, Natural gasses.
- Most familiar fuels consist primarily of hydrogen and carbon.
- They are called **hydrocarbon fuels** and are denoted by the general formula ***CnHm.***
- Hydrocarbon fuels exist in all phases, some examples being coal, gasoline, and natural gas.

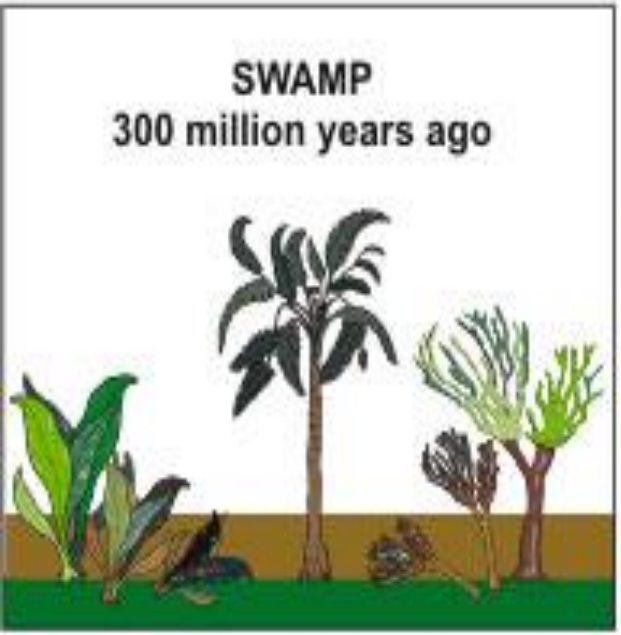
Photosynthesis



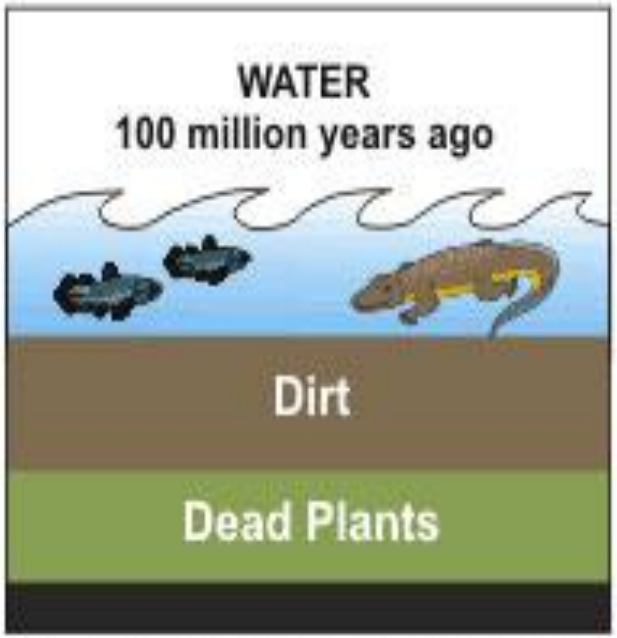
$6CO_2$ Carbon dioxide + $6H_2O$ Water $\xrightarrow{\text{Light}}$ $C_6H_{12}O_6$ Sugar + $6O_2$ Oxygen


Carbohydrates
$C_x(H_2O)_y$
Pressure +
Heat
Hydrocarbons
C_xH_y

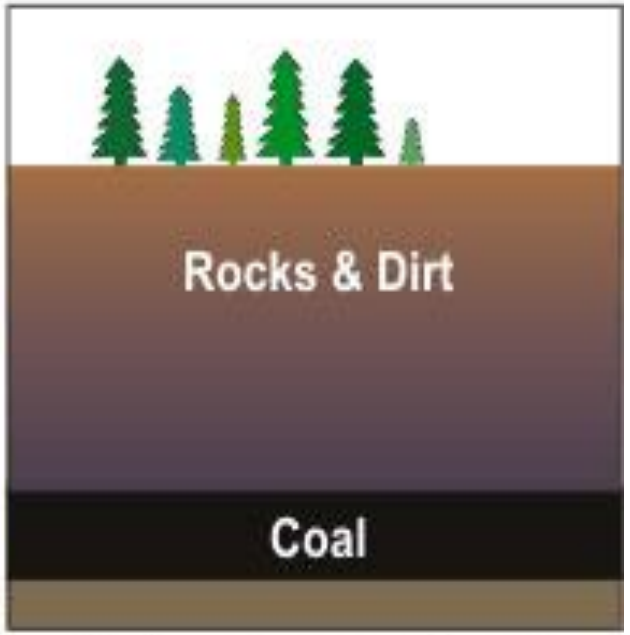
Coal



Before the dinosaurs, many giant plants died in swamps.

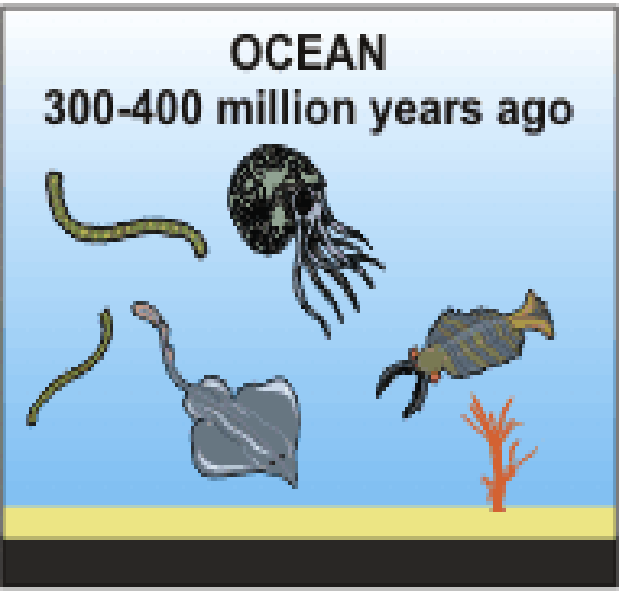


Over millions of years, the plants were buried under water and dirt.

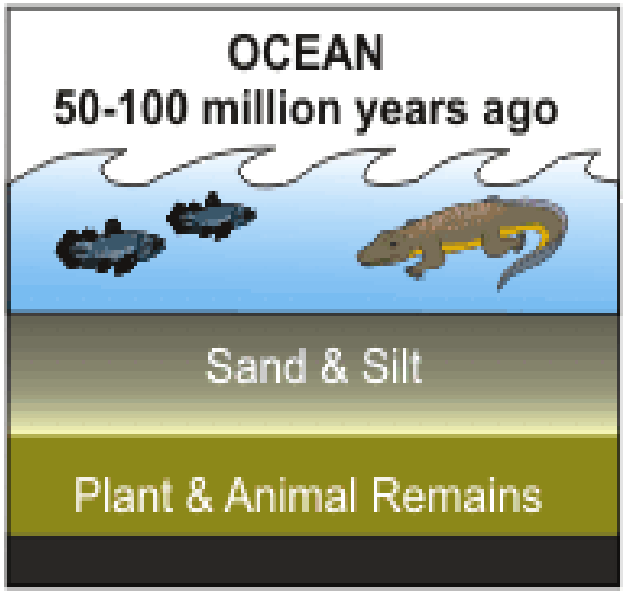


Heat and pressure turned the dead plants into coal.

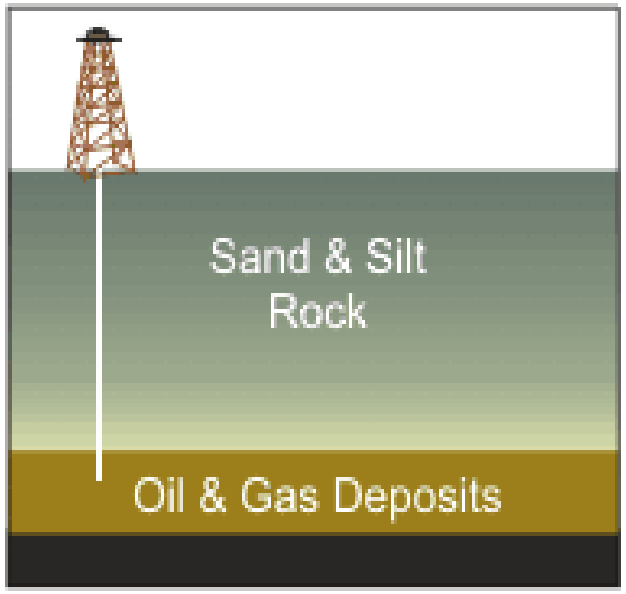
PETROLEUM & NATURAL GAS FORMATION



Tiny sea plants and animals died and were buried on the ocean floor. Over time, they were covered by layers of silt and sand.

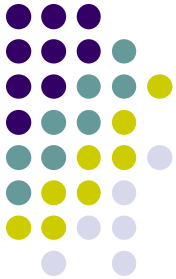


Over millions of years, the remains were buried deeper and deeper. The enormous heat and pressure turned them into oil and gas.



Today, we drill down through layers of sand, silt, and rock to reach the rock formations that contain oil and gas deposits.

Fossil Fuels are formed from Living things millions of years ago. There are three main Fossil Fuels:



Coal, Oil and Gas

Fossil Fuels are *Finite Fuels* ie.They will run out in the future and cannot be *regenerated.*

- **Oil**: This was formed by *dead sea creatures* falling to the sea-bed where they were subjected to chemical change by Bacteria.

Coal: This was formed by the *decay of Vegetation* which was subjected to heat and pressure over a very long period of time.

Gas was formed in much the same way as Oil. It is often collected when drilling for Oil.

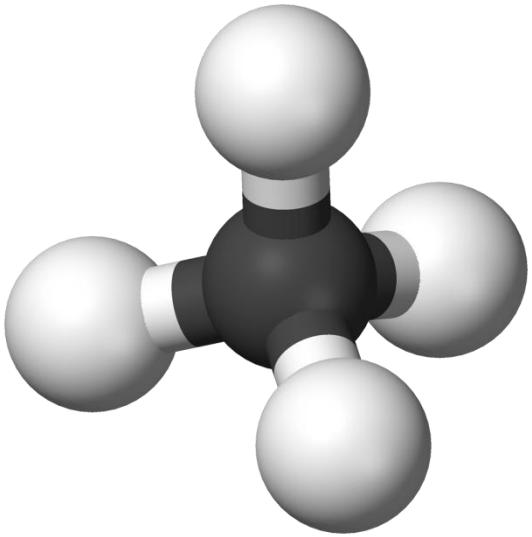
Alternative sources of Energy which are **Renewable** must be found eg. ***Solar, Wind Tide and Wave Power.***

Hydrocarbon Chemistry

- Hydrocarbons are obtained from the natural sources example *Coal, Petroleum, Natural Gas*.

- Depending on the properties hydrocarbons are divided into **2 groups**:

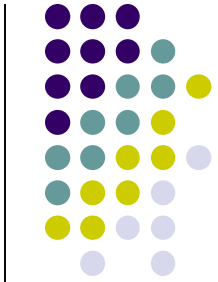
1. Aliphatic Hydrocarbons (open chain compounds)
2. Cyclic hydrocarbons (closed chain compounds)



Methane Molecule, CH_4

Petroleum

Petroleum

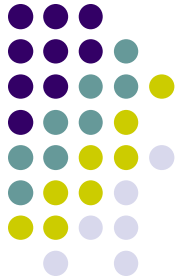


- Petroleum is a complex mixture of liquid hydrocarbons, chemical compounds containing hydrogen and carbon, occurring naturally in underground reservoirs in sedimentary rock.
- Coming from the Latin petra, meaning ***rock***, and oleum, meaning ***Oil***, the word "***Petroleum***" is often interchanged with the word "*Oil*".
- Broadly defined, it includes both primary (unrefined) and secondary (refined) products.

- Oil is the largest traded commodity worldwide, either through crude oil or through refined products.

- Although oil supply continues to grow in absolute terms, its share in global total energy supply has been decreasing, from over 45% in 1973 to around 35% in recent years.

What Units are Used to Express Oil?



- Liquid fuels can be measured by their mass or volume. Within each of these measurements, several units are used in the oil industry:
- The most widely used unit of mass (weight) to measure oil is the metric ton (or tonne).
- For instance, tankers in the oil industry are often described on the basis of their capacity in tonnes, where an Ultra Large Crude Carrier (ULCC) is defined as being able to carry over 320 000 tonnes.

- The original unit for most liquid and gaseous fuels is ***Volume***.
- Liquids can be measured by the Litre, the Barrel, or the Cubic Metre.
- A common example of the use of volume as the unit of measurement is in the price of oil, quoted in ***Dollars Per Barrel***.

- As liquid fuels can be measured by their mass or their volume, it is essential to be able to convert one into the other.
- In order to make this conversion, the **specific gravity** or density of the liquid is needed.

- As liquid fuels can be measured by their mass or their volume, it is essential to be able to convert one into the other.
- In order to make this conversion, the specific gravity or density of the liquid is needed.

- Because crude oil contains a wide range of hydrocarbons from the lightest to the heaviest, the characteristics, including the density, of individual crude oils vary greatly.
- Similarly, the density of the different petroleum products varies substantially between the products.

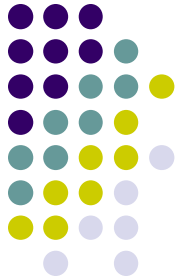
- The density can be used to classify petroleum products from light to heavy, where for example:

(Liquefied Petroleum Gas) LPG is considered light at 520 kg/m^3 while fuel oil is a heavy product at over 900 kg/m^3.

Note

- Many countries and organizations use the tonne of oil equivalent (toe) when publishing energy balances.
- The toe unit which is based on calorific properties is used to compare oil with other energy forms and should not be confused with the mass measurement in tonnes.
- 1 toe = 11630 kwh

How to Make the Conversion from Volume to Mass?



- The oil industry in different parts of the world uses different units of measurement.
- For example, in Europe the *Metric Ton* is commonly accepted as the unit of measurement, ***while*** in the United States, the volume unit *Barrel* is the unit of choice.
- In Japan, *Volume* is also used for measuring oil supply and demand; **however, the standard unit is the *Cubic Metre*.**

- As so many different units, both volume and mass, are used in the world, it is essential to be able to convert them into a common unit for purposes of comparison.
- The oil industry internationally uses mainly barrels (bbl) as its reference unit.
- For certain flows such as production and demand, it is barrels per day (b/d) which is commonly used.

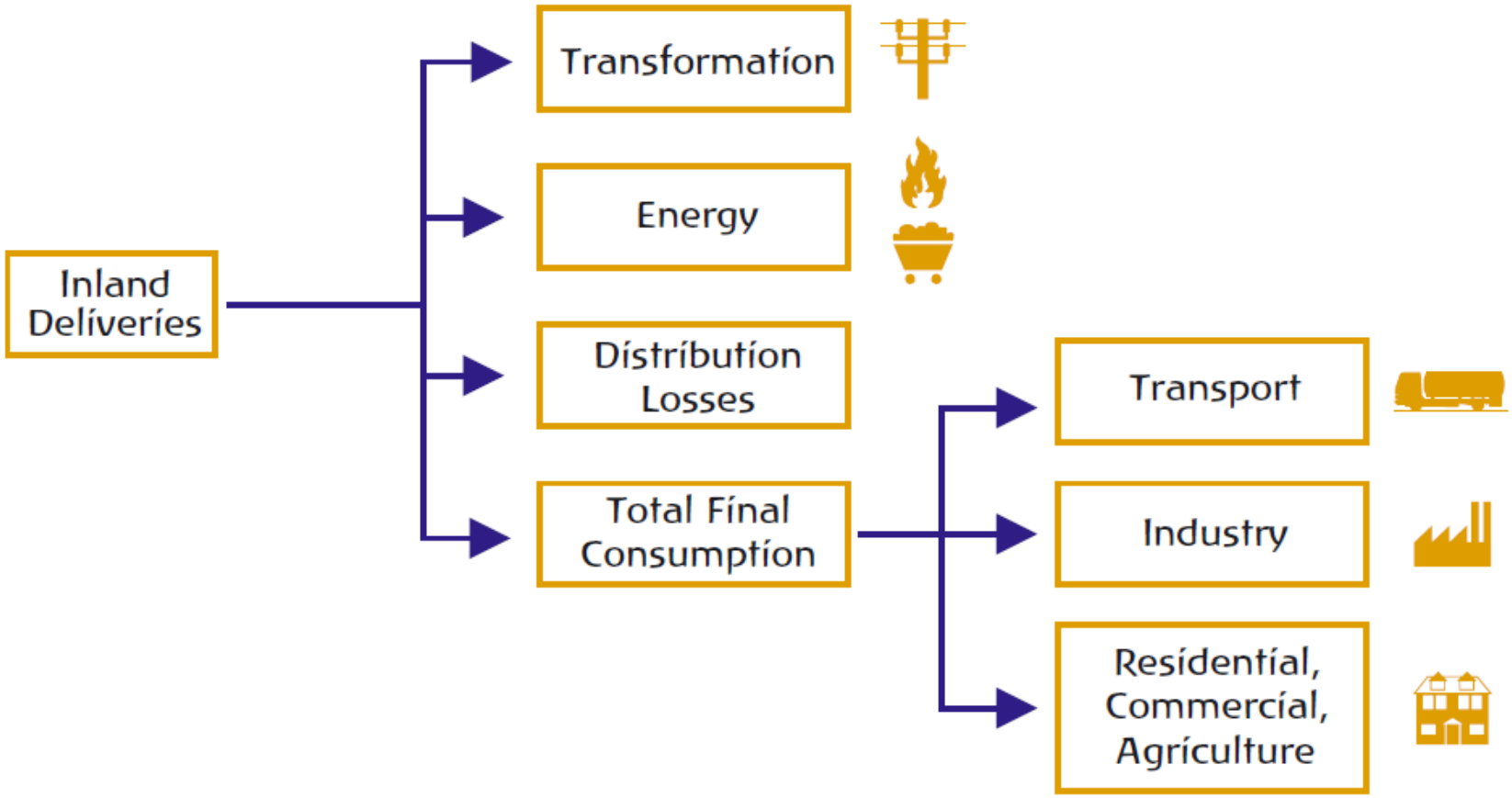
- A **barrel** is one of several units of volume applied in various contexts; there are **dry barrels**, **fluid barrels** (such as the **U.K. beer barrel** and **U.S. beer barrel**), **oil barrels**, and so forth.

- Density is defined as mass per unit volume, i.e. tonne/barrel.
- The specific gravity is the relative weight per unit volume (or density) of a given substance compared to that of water.
- The density of water is 1g/cm^3.
- Motor gasoline, for example, has a lower density as it is much lighter for the same volume.

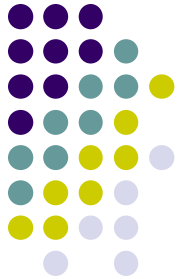
- The **specific gravity** of motor gasoline is therefore smaller than 1.
- Since volume changes with changes in temperature, data on specific gravity are reported with a reference to a specific temperature (for petroleum, the reference is usually 15 degrees Celsius).
- _Moreover, specific gravity is often quoted as a percentage, e.g. a specific gravity of 0.89 is shown as 89.

Oil Consumption

Figure 4.7 ● Oil Consumption by Sector

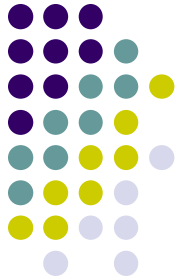


Consumption of oil in the transformation sector



- The quantities of oil used in the process of transformation of oil to another energy form should be reported in the transformation sector.
- This largely consists of oil products burnt in order to produce electricity or heat

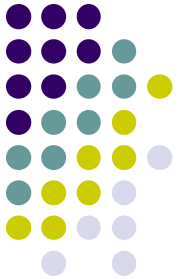
Consumption of oil in the energy sector



- Besides being used in the transformation sector as detailed above, oil products can be used by the energy industry to support energy production.

- This is, for example, oil used in a coal mine in support of the extraction and preparation of coal within the coal-mining industry.

Oil transport and distribution losses

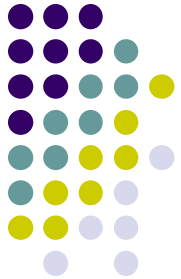


- The transportation and distribution of petroleum products often involve multiple episodes of handling and storage.
- There are four main means for transporting petroleum as it moves from the wellhead to the refinery and on to the final consumer:

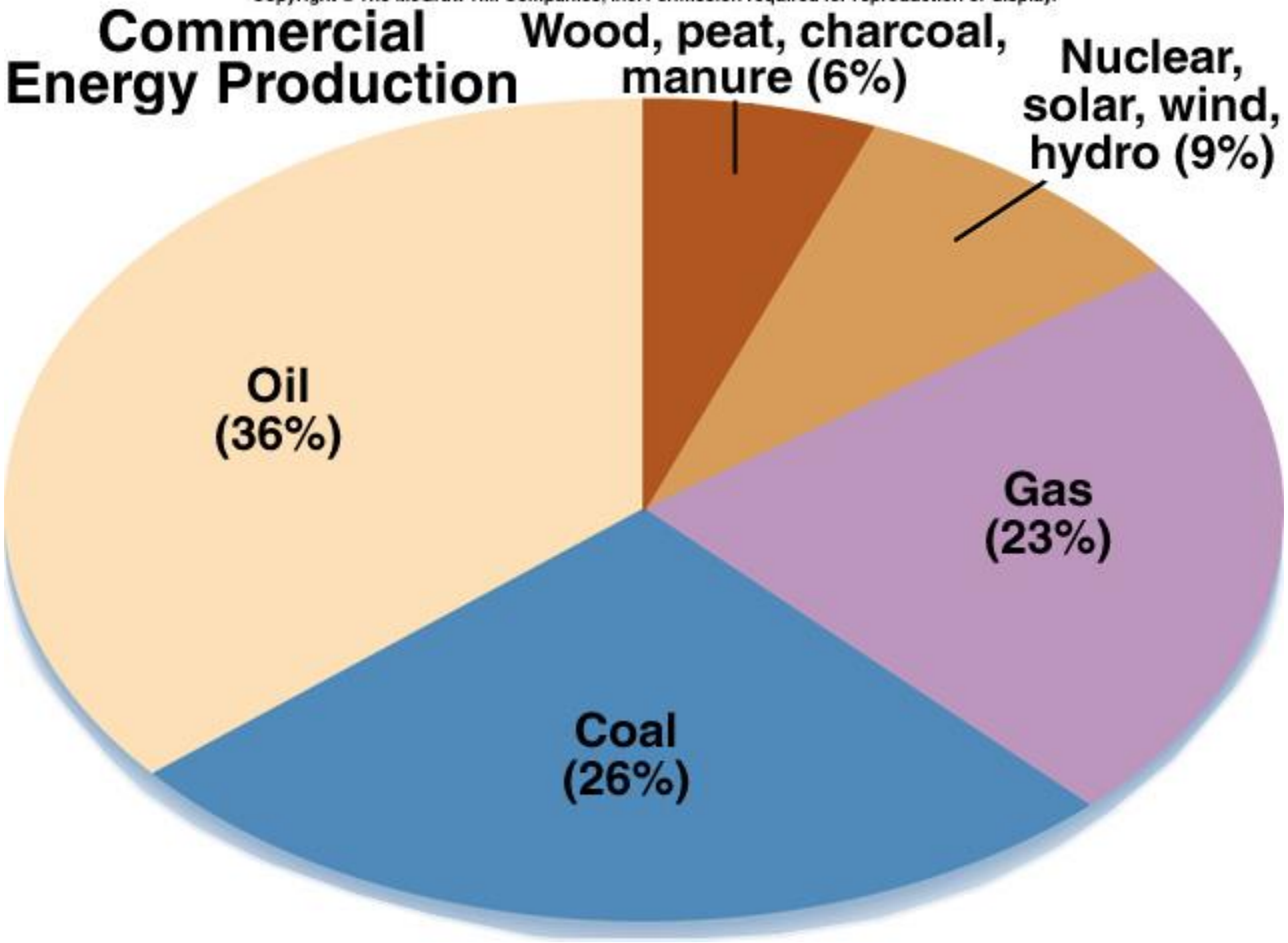
  by sea, pipeline, railway and roadway.

episodes

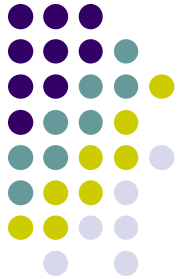
Final Consumption



- Final consumption is all energy used by final consumers in the transport, industry, and other sectors (*Residential, Commerce, Public Services And Agriculture*).
- It excludes all oil used for transformation and/or own use of the energy-producing industries.



20 Richest Countries consume:

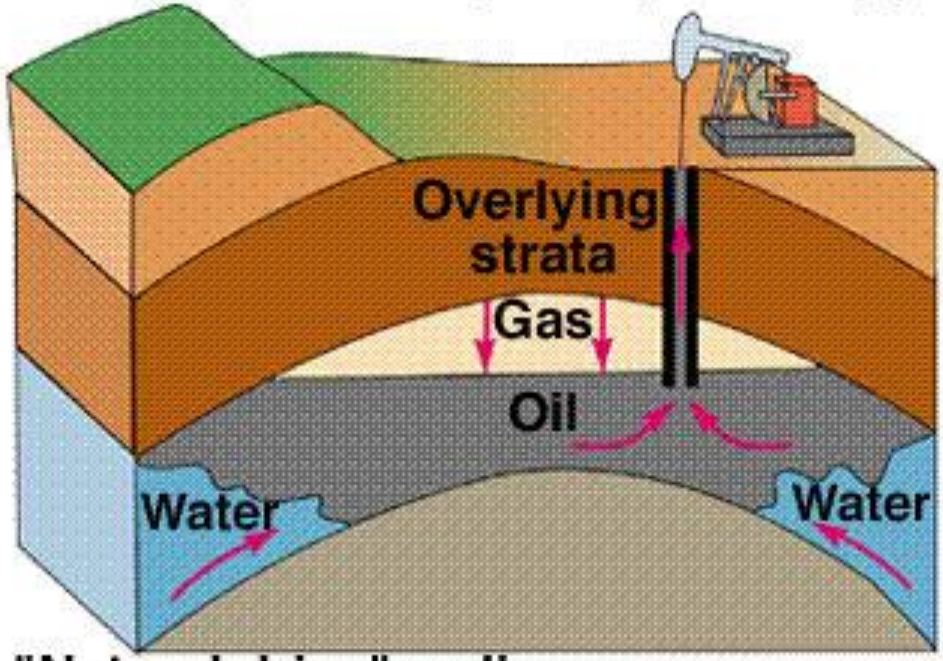


- 50% of coal
- 80% of natural gas
- 65% of oil

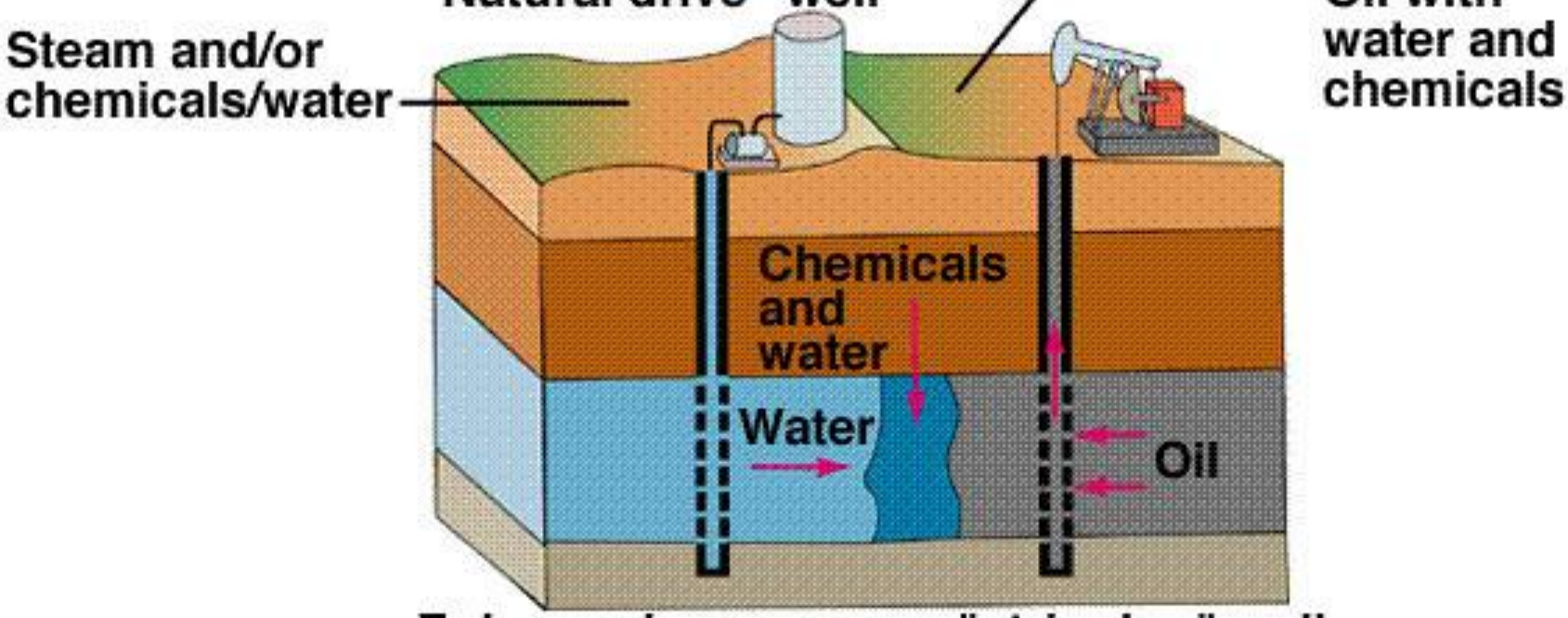
OIL (Petroleum)

Buried organic matter rich in hydrocarbons

Petroleum Recovery Process

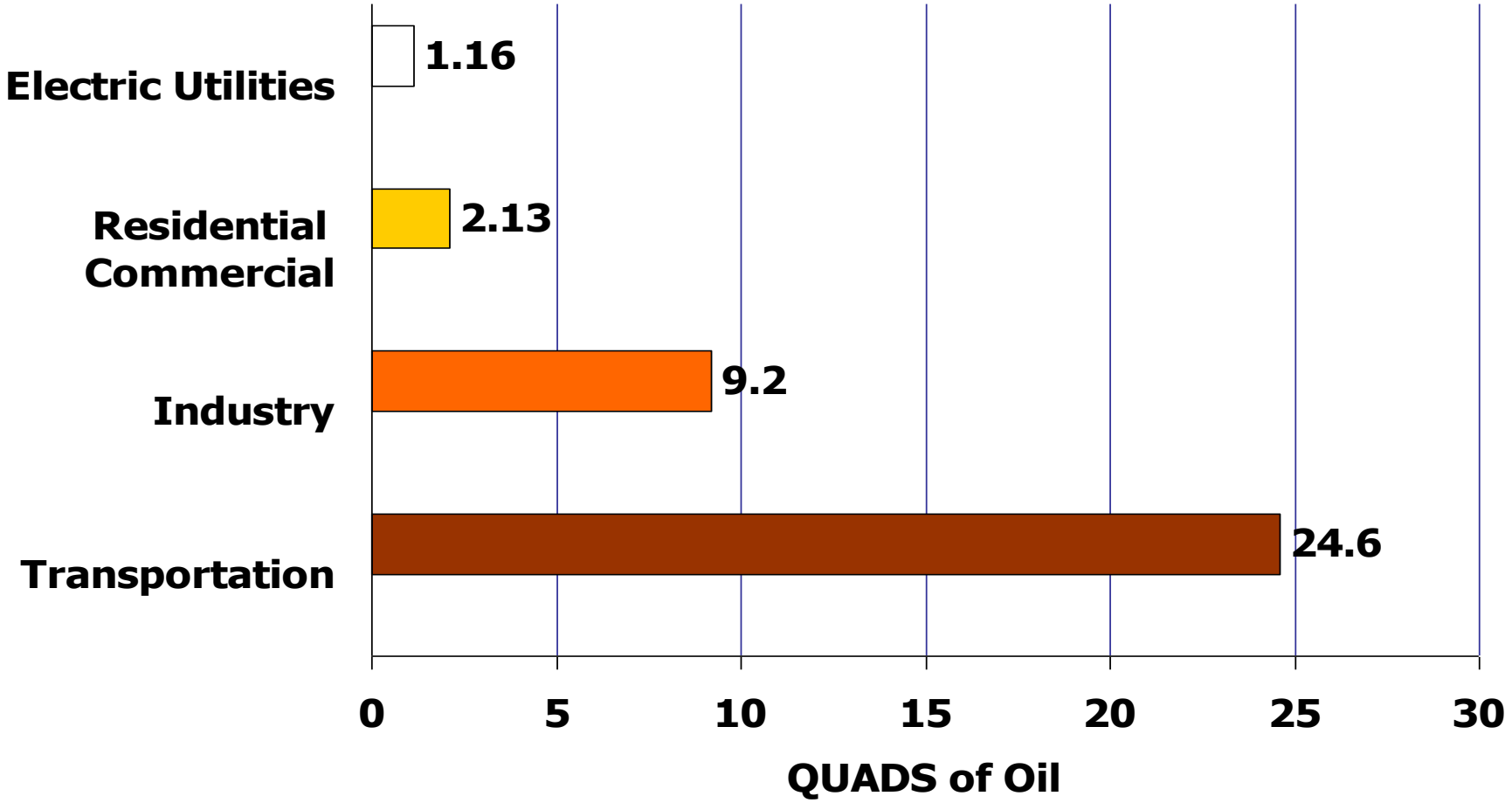


"Natural drive" well

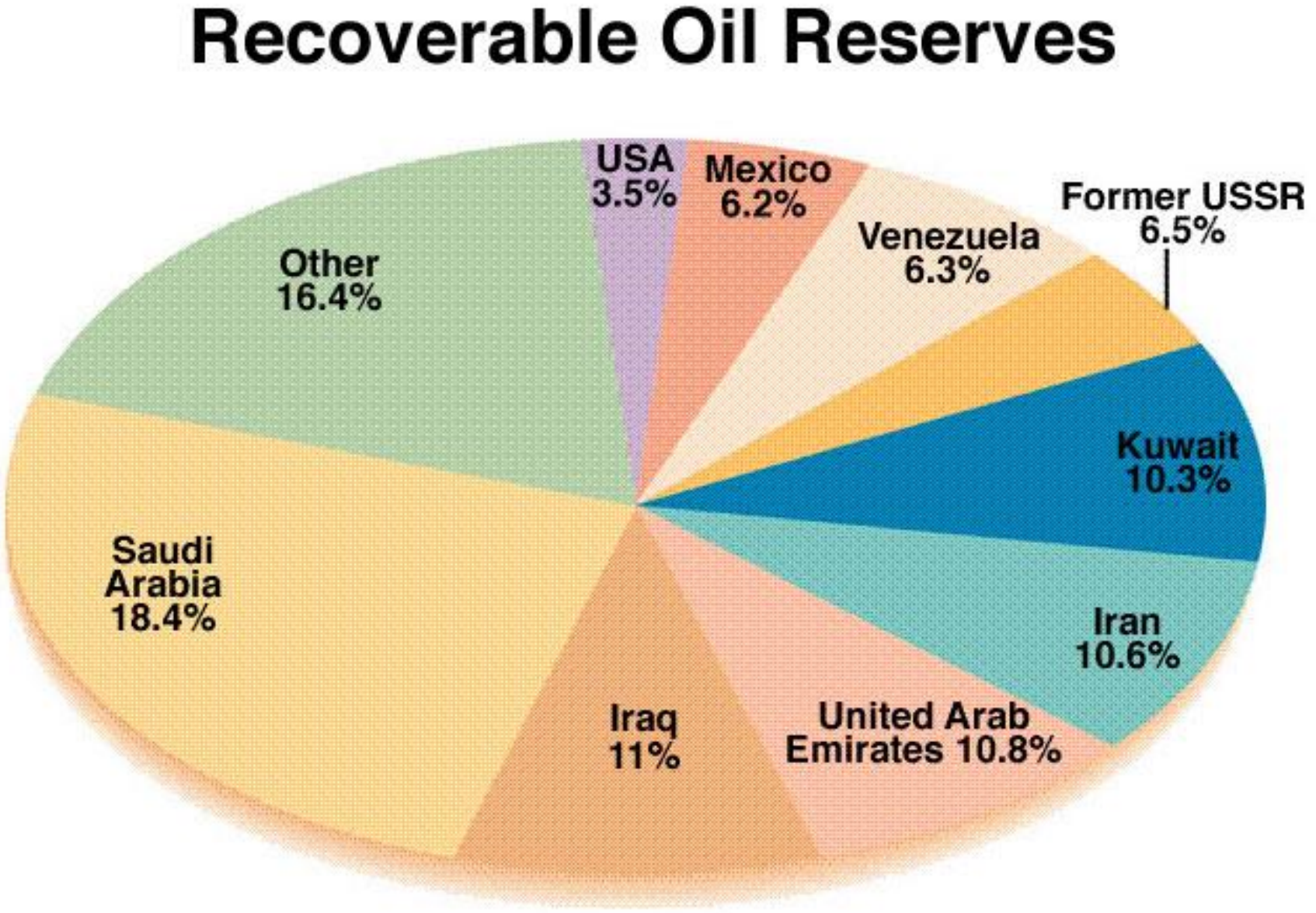


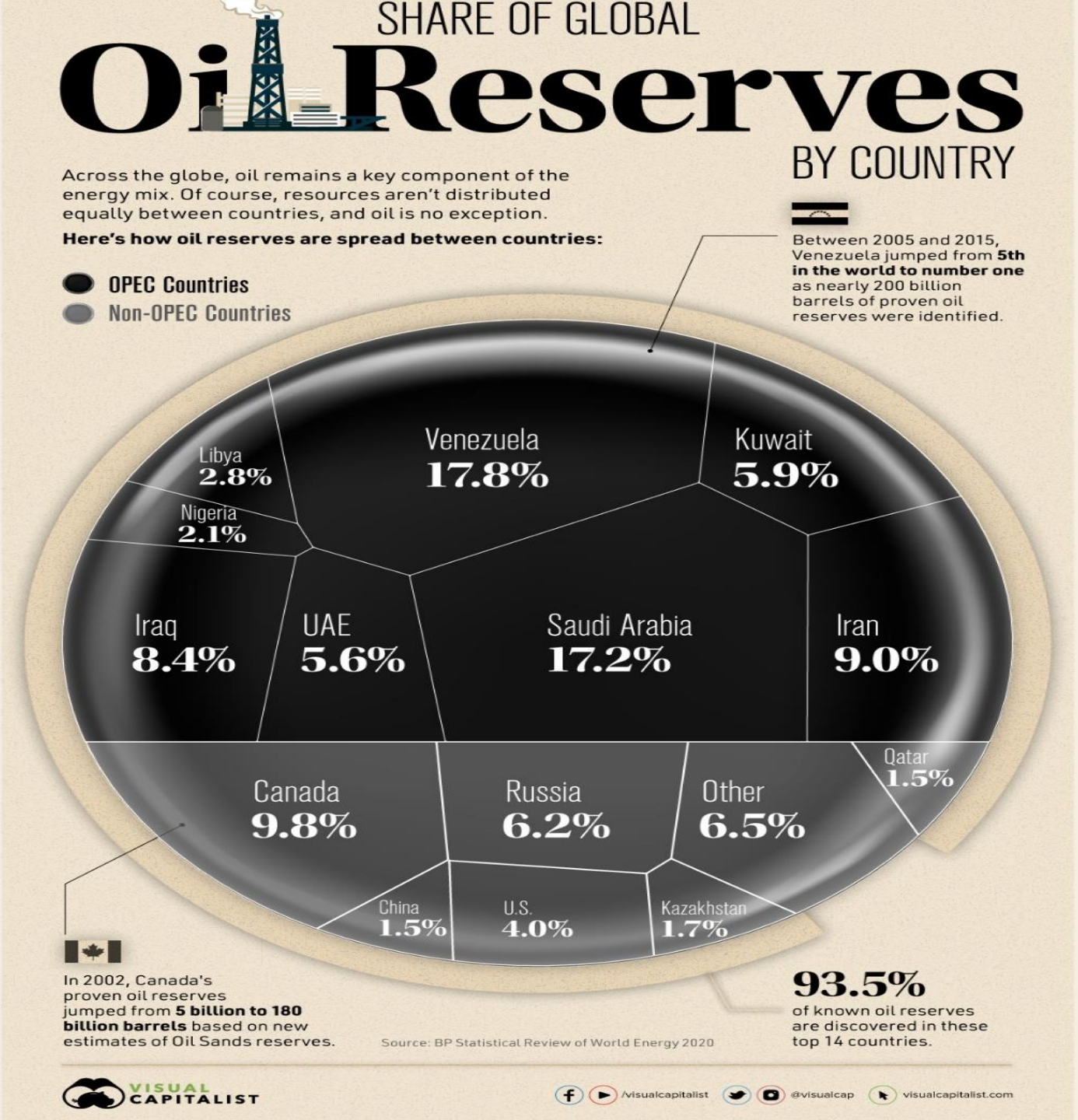
Enhanced recovery or "stripping" well

Oil Consumption by Sector (1998)



Recoverable Oil Reserves




SHARE OF GLOBAL
Oil Reserves
BY COUNTRY
Across the globe, oil remains a key component of the energy mix. Of course, resources aren't distributed equally between countries, and oil is no exception.
Here's how oil reserves are spread between countries:
OPEC Countries
Non-OPEC Countries
Between 2005 and 2015, Venezuela jumped from 5th in the world to number one as nearly 200 billion barrels of proven oil reserves were identified.
Venezuela 17.8%
Kuwait 5.9%
Libya 2.8%
Nigeria 2.1%
Iraq 8.4%
UAE 5.6%
Saudi Arabia 17.2%
Iran 9.0%
Qatar 1.5%
Canada 9.8%
Russia 6.2%
Other 6.5%
China 1.5%
U.S. 4.0%
Kazakhstan 1.7%
In 2002, Canada's proven oil reserves jumped from 5 billion to 180 billion barrels based on new estimates of Oil Sands reserves.
93.5%
of known oil reserves are discovered in these top 14 countries.
Source: BP Statistical Review of World Energy 2020
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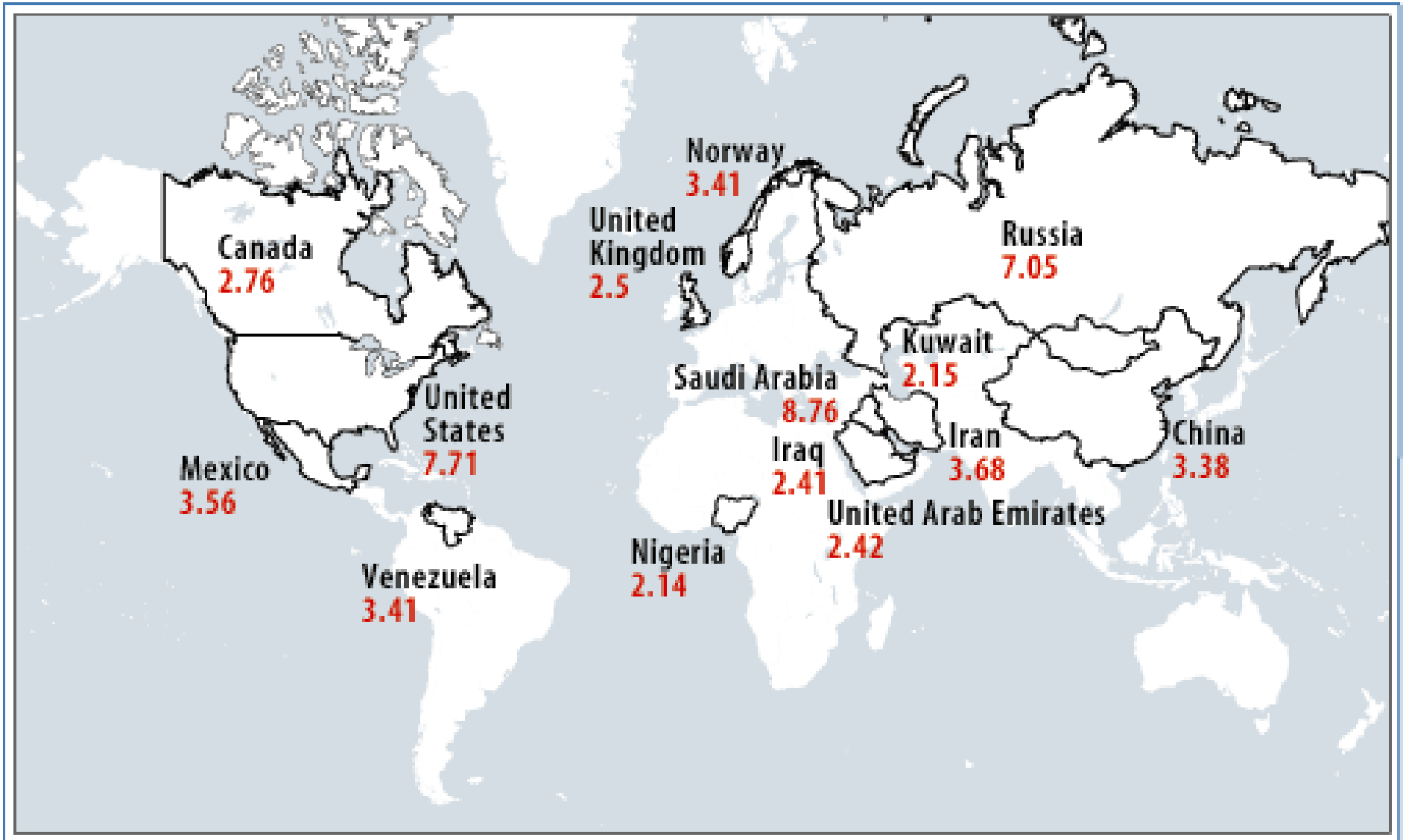
visualcapitalist.com

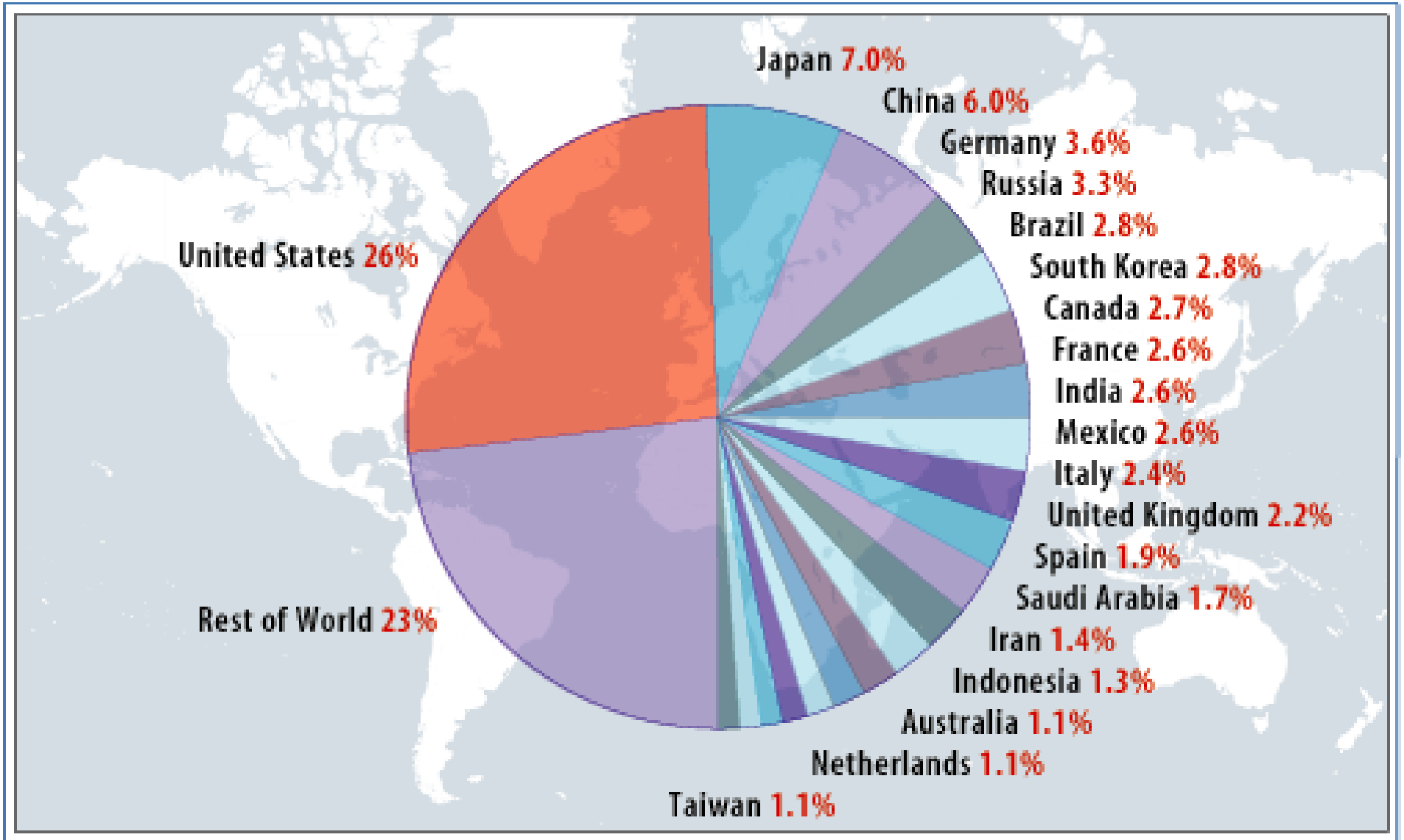

U.S.
Canada
Saudi Arabia
Venezuela
Mexico
Nigeria
Iraq
Norway
Angola
Colombia
Kuwait
Other nations
Where Does U.S. Oil Come From?

Where Is the World's Oil Currently Produced?

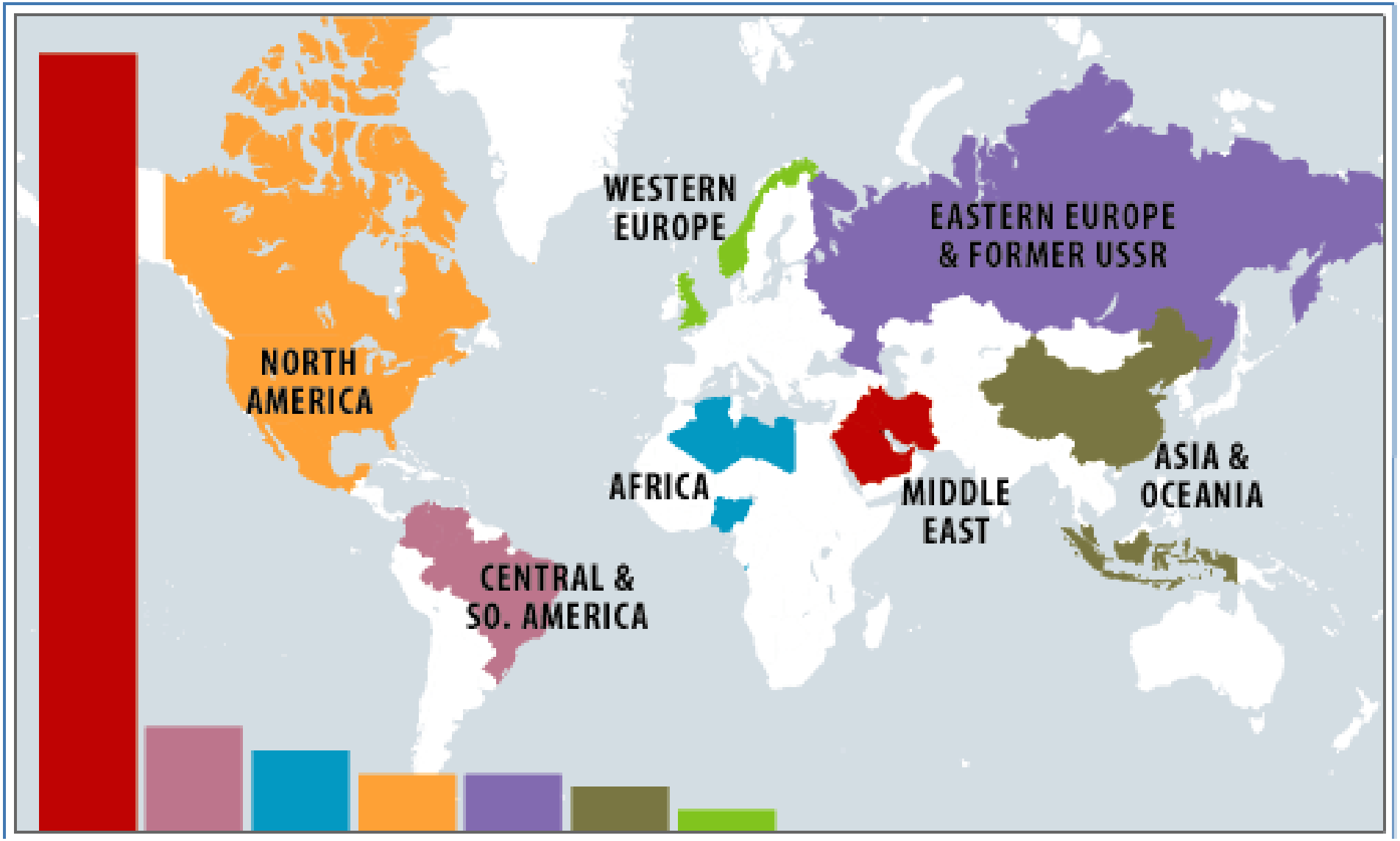


Numbers indicate millions of barrels per day (m/b/d)

Who Consumes the Most Oil?



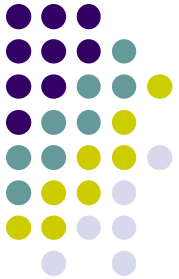
Where Are the World's Oil Reserves?



Some surprising facts about U.S. oil consumption and more.

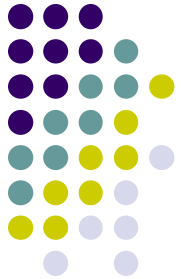
- There are 42 gallons of oil in a barrel.
- The world consumes 3.1 billion gallons of oil a day.
- The United States is the largest producer and consumer of oil, using 25 percent of the world's supply.
- World oil demand is projected to increase from 76 million barrels per day in 2000 to 118.9 million barrels per day in 2020. U.S. demand is projected to reach 27 million barrels a day by 2020, 64 percent of which will have to be imported.
- Light trucks (a category that includes SUVs, pickups and minivans) comprise 46 percent of all cars sold in the United States today. These vehicles are less fuel efficient and subject to fewer environmental standards and laws than conventional automobiles.
- American light trucks account for 10 percent of the world's oil consumption and 5 percent of the world's greenhouse gases.

Proven Oil Reserves



- 465 billion barrels consumed
- 1 trillion barrels left
- 22 billion consumed a year
- 45 years to go! Party now!

Global trends in oil

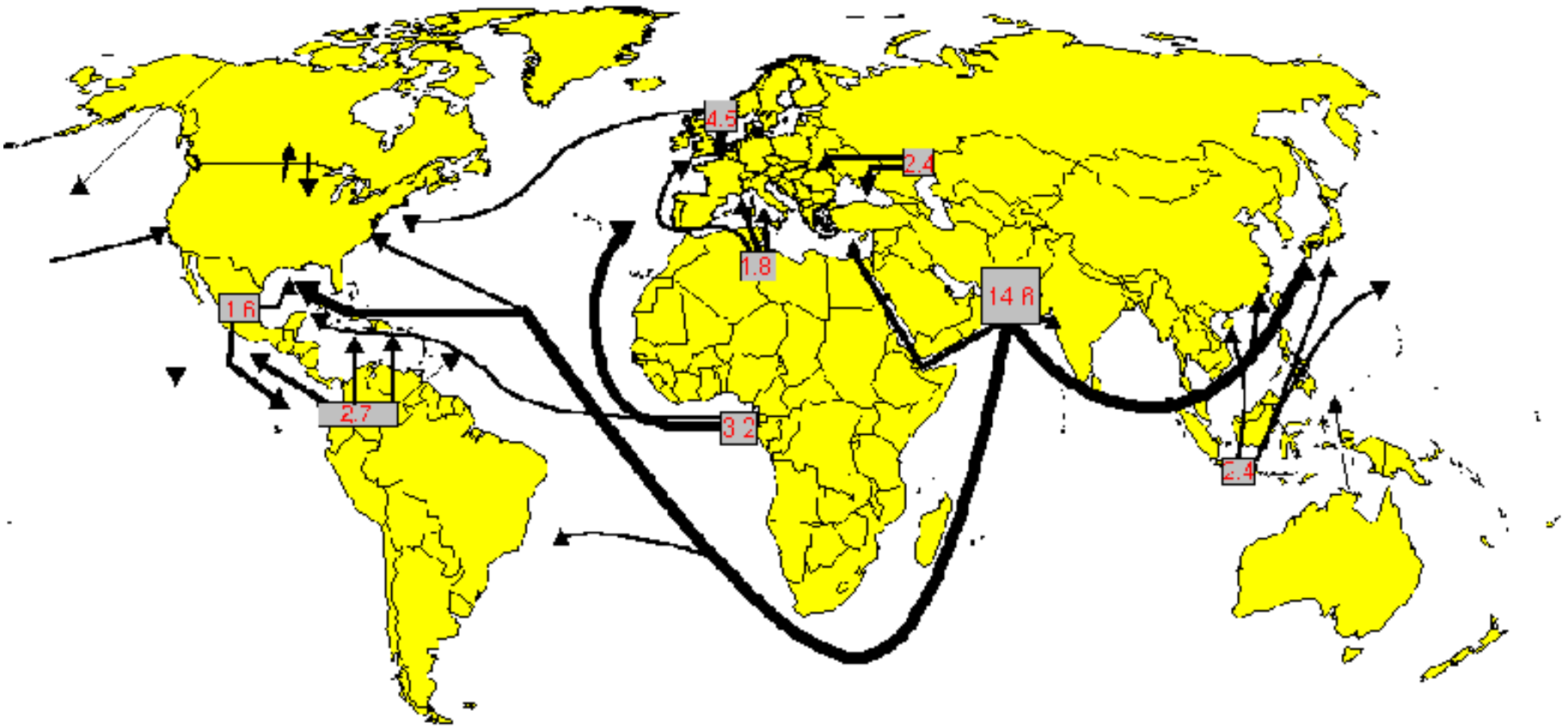


- Growing use in China (+10%/year)
- Japan, Europe depend on Mideast
- New reserves around Caspian Sea
  - Nearly size of Saudi Arabia
- Increasing source of major wars, human rights abuses

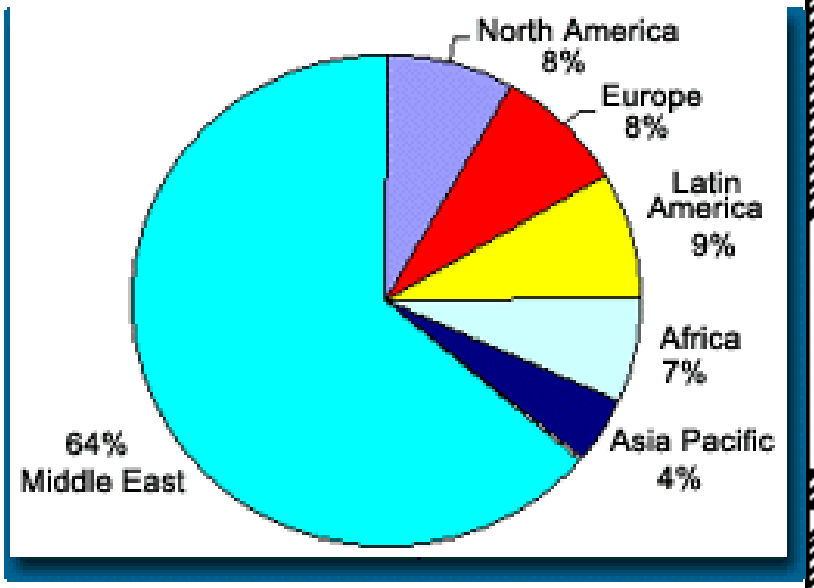
Kuwait oil well fires, 1991

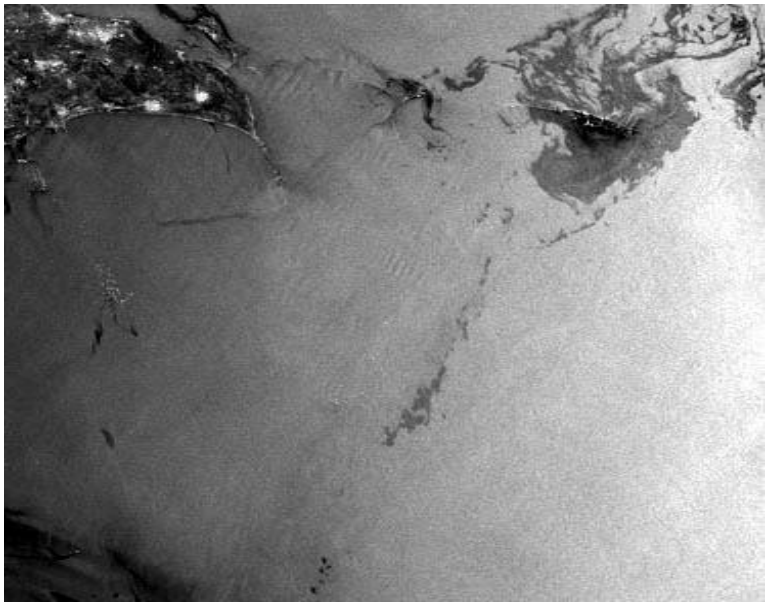
World Crude Oil Flows 1997

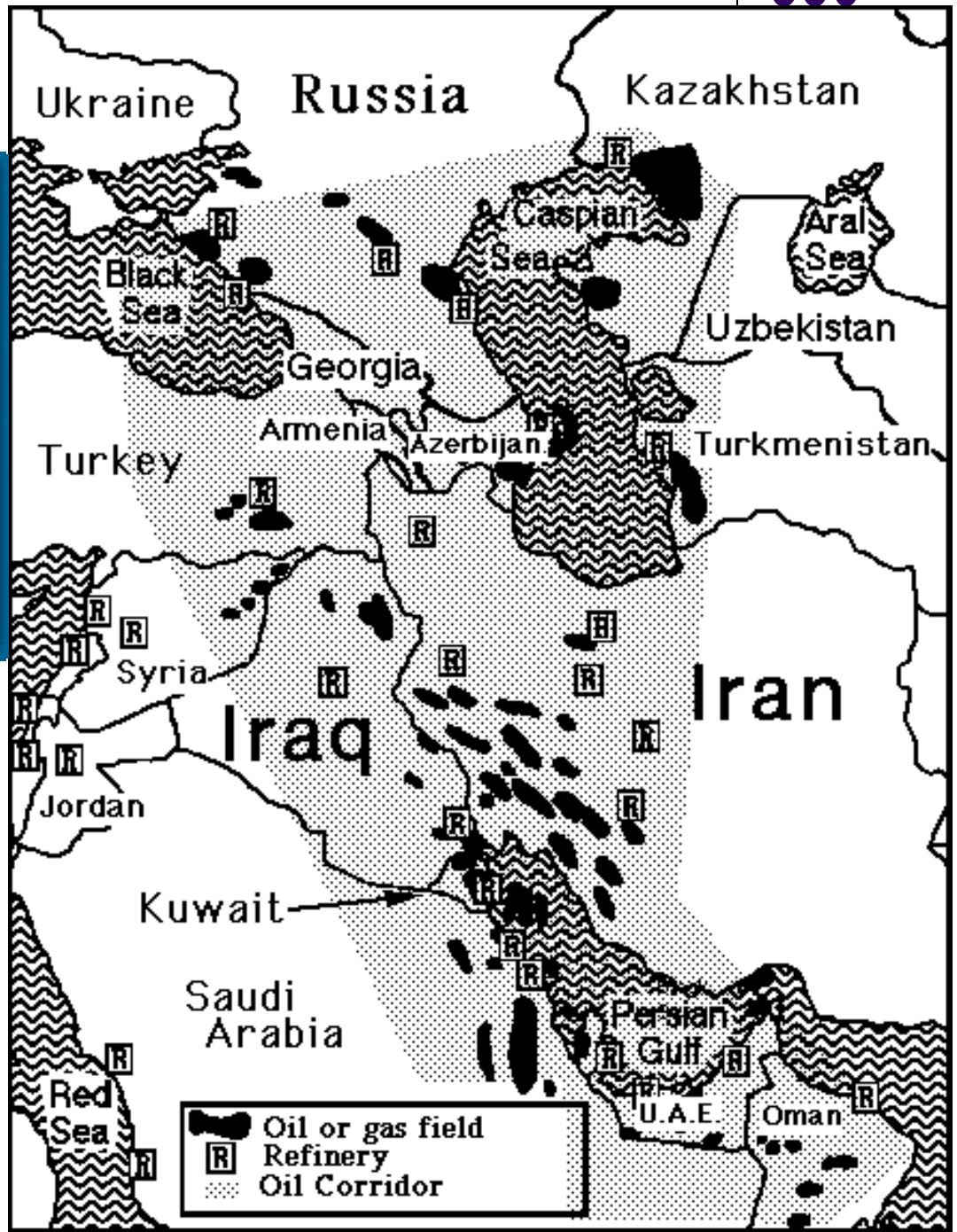
34.8 Million Barrels Per Day



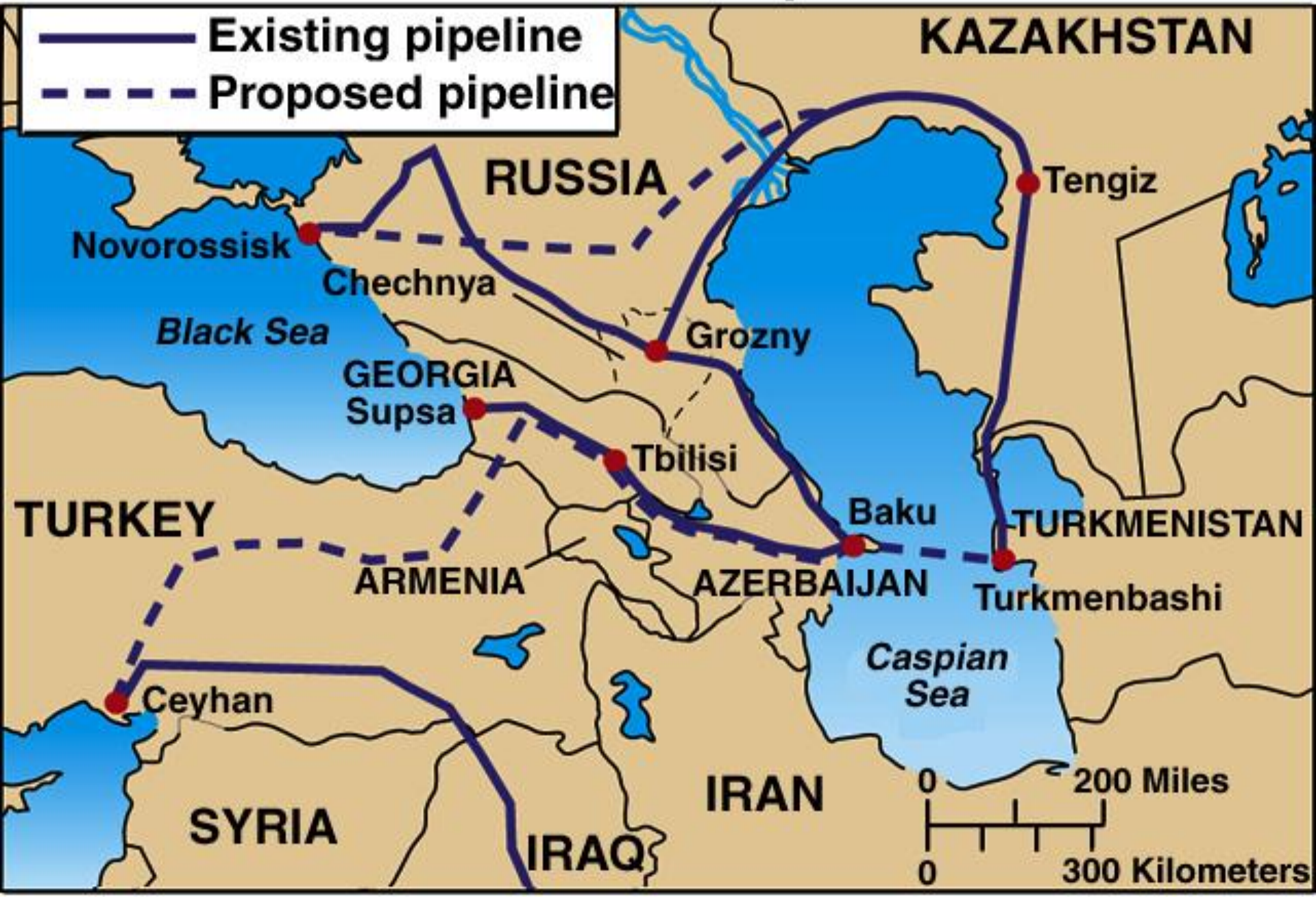
Energy Information Administration


North America
8%
Europe
8%
Latin
America
9%
Africa
7%
Asia Pacific
4%
64%
Middle East




Ukraine
Russia
Kazakhstan
Caspian
Sea
Aral
Sea
Black
Sea
Uzbekistan
Georgia
Armenia
Azerbijan
Turkmenistan
Turkey
Syria
Iran
Iraq
Jordan
Kuwait
Saudi
Arabia
Persian
Gulf
Red
Sea
U.A.E.
Oman
Oil or gas field
Refinery
Oil Corridor

Mideast Oil Pipeline



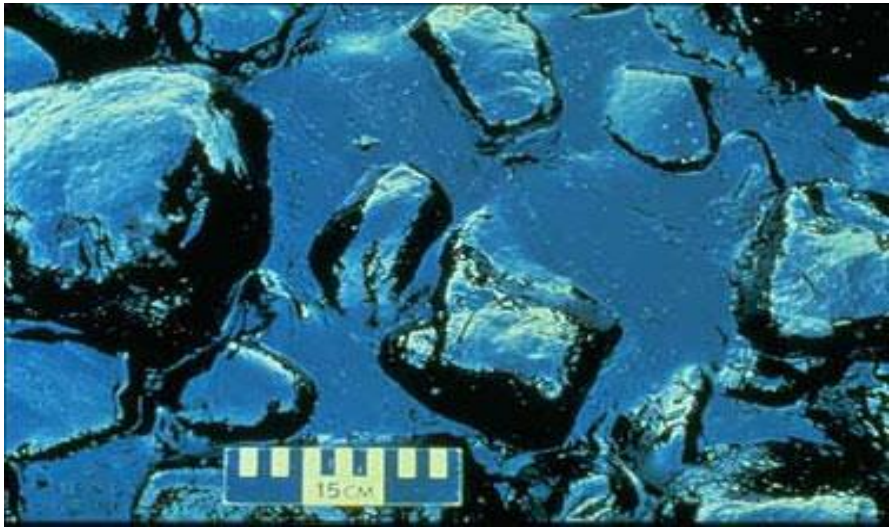
Oil & Natural Gas Pipelines

Potential Export Routes

Unocal / Delta Central Asia Oil Pipeline

Caspian Pipeline Consortium

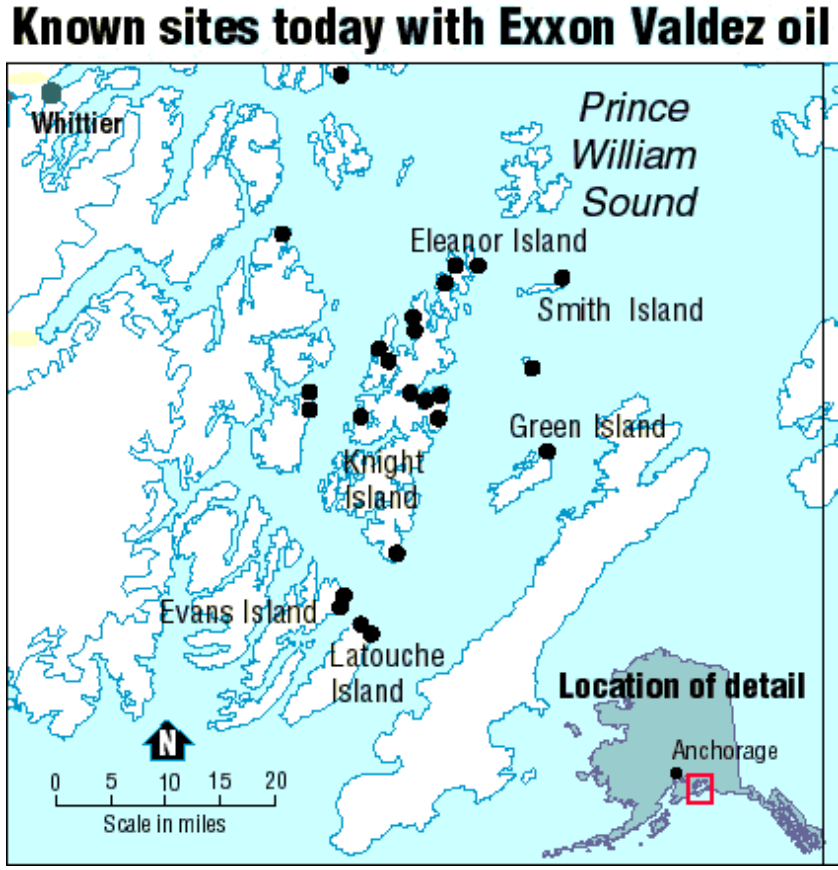
Attempts to contain spill

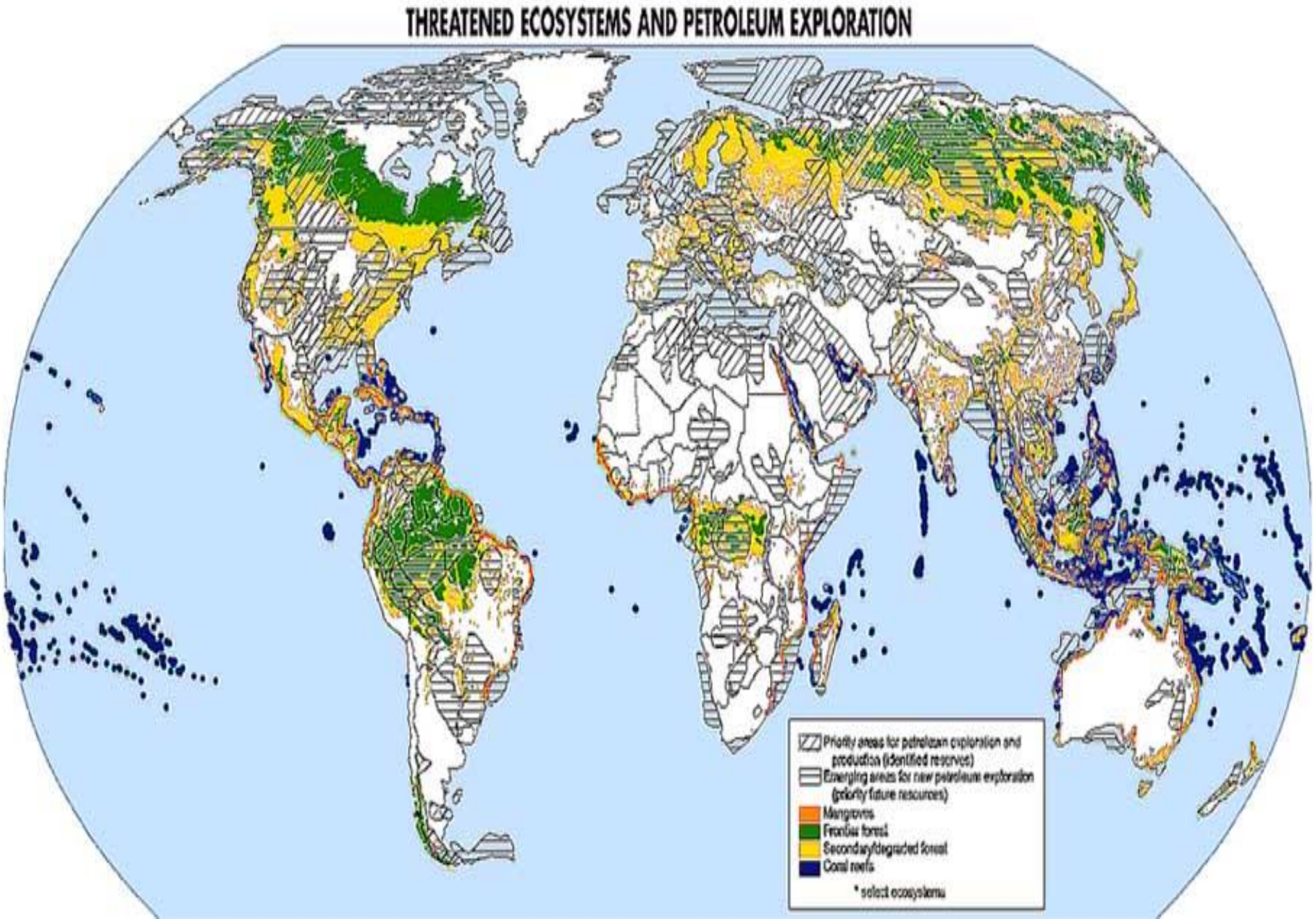


Clean-up efforts

Prince William Sound fishing industry damaged

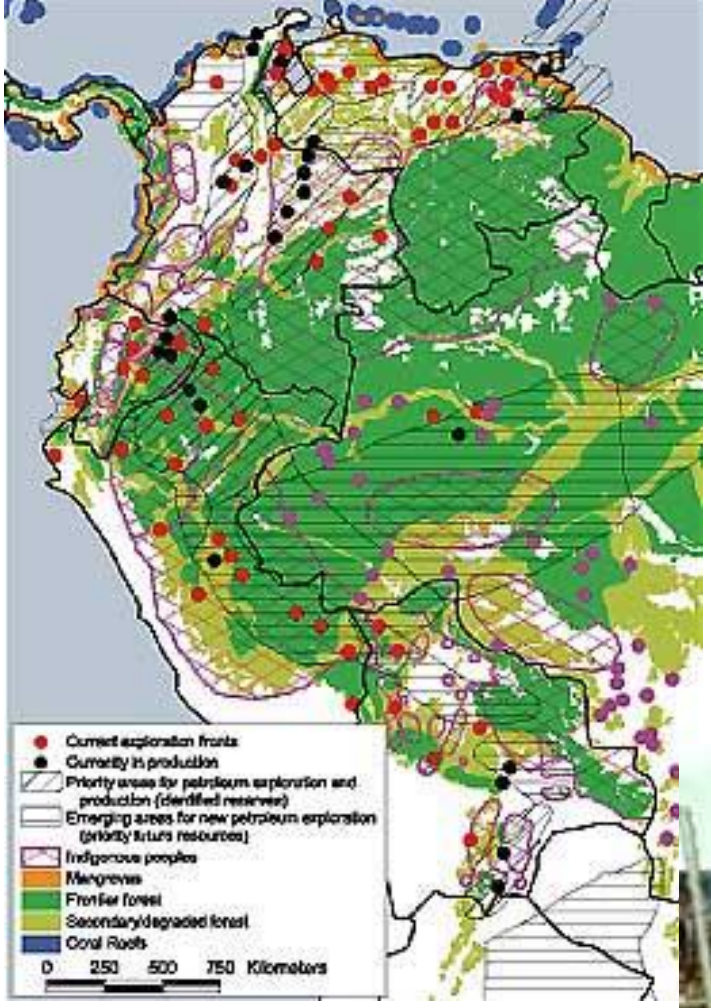
Exxon Valdez, an oil tanker off the coast of Alaska, hit a reef in March of 1989, spilling more than 11 million gallons of oil into the ocean.

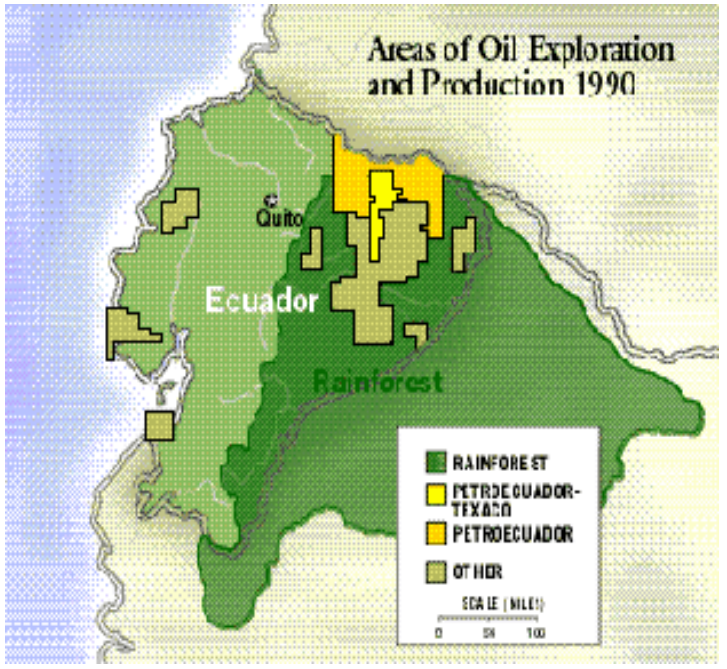



THREATENED ECOSYSTEMS AND PETROLEUM EXPLORATION
Priority areas for petroleum exploration and production (identified reserves)
Emerging areas for new petroleum exploration (priority future resources)
Mangroves
Frontier forest
Secondary/degraded forest
Coral reefs
* select ecosystems

Oil in Ecuador

- Ecuador 2nd largest S. America producer
  - 70% of exports
- Drilling in Amazon rainforest





Opposition to oil companies

- Construction of roads, pipelines on Indian lands.
- Displacement of Indians, deforestation.
- Oil leaks into rivers larger than Valdez spill.

Ecuador Indian occupations

Texaco withdrew 1992, Arco met demands

Lawsuit against Texaco in U.S. courts, 19

Oil in Nigeria

Largest producer in Africa, mainly In Niger Delta

Nigeria had military governments in 1990s

Environmental problems in Niger Delta region

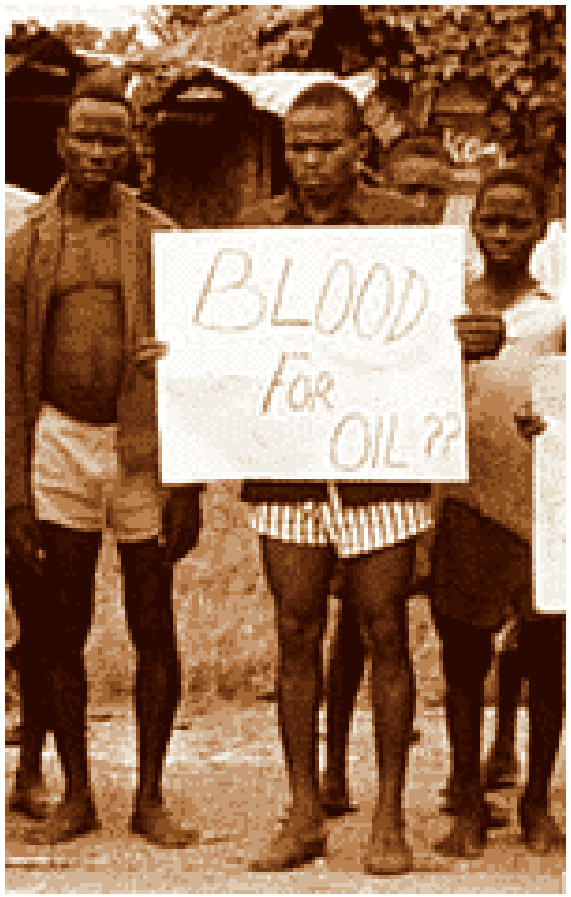
Homeland of Ogoni, Ijaw groups

Gas flaring hazards

Oil spills in mangrove swamp

Ogoni environmental protests

Oil companies collude with military



Many Ogoni killed by military

Shell Oil pays, transports soldiers

Ogoni leader Dr. Ken Saro-Wiwa executed in 1995

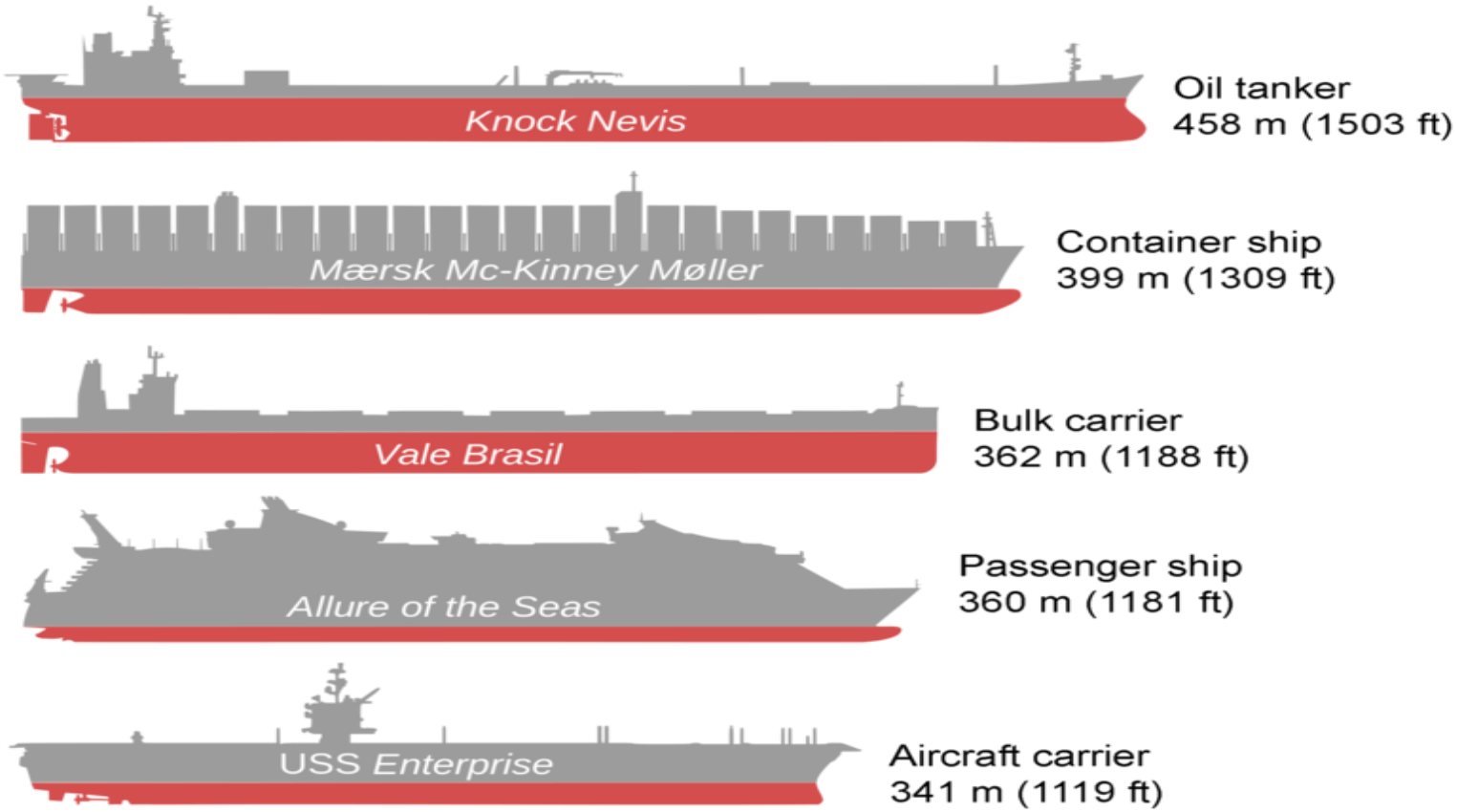
Nigerian women protest, 2002

Ijaw women occupy Chevron oil docks

Protest against pollution, lack of local jobs

- An **oil tanker**, also known as a **petroleum tanker**, is a merchant ship designed for the bulk transport of oil.
- There are two basic types of oil tankers: the **crude tanker** and the **product tanker**.[3] Crude tankers move large quantities of unrefined crude oil from its point of extraction to refineries.[3] Product tankers, generally much smaller, are designed to move refined products from refineries to points near consuming markets.

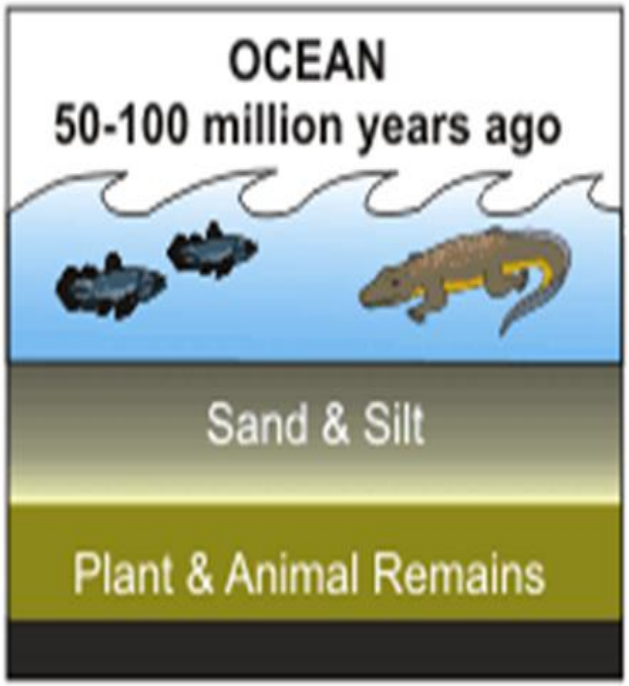
- **Ultra Large Crude Carriers** (ULCCs) of 550,000 DWT



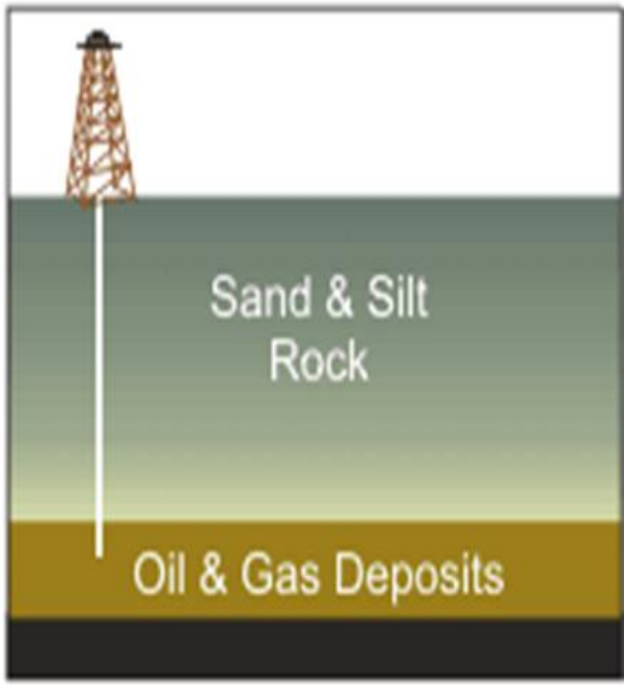
Deadweight tonnage or tons deadweight (DWT) is a measure of how much weight a ship can carry. It is the sum of the weights of cargo, fuel, fresh water, ballast water, provisions, passengers, and crew.

PETROLEUM & NATURAL GAS FORMATION

Tiny sea plants and animals died and were buried on the ocean floor. Over time, they were covered by layers of silt and sand.



Over millions of years, the remains were buried deeper and deeper. The enormous heat and pressure turned them into oil and gas.



Today, we drill down through layers of sand, silt, and rock to reach the rock formations that contain oil and gas deposits.

Fossil Fuels are formed from Living things millions of years ago. There are three main Fossil Fuels:

Coal, Oil and Gas

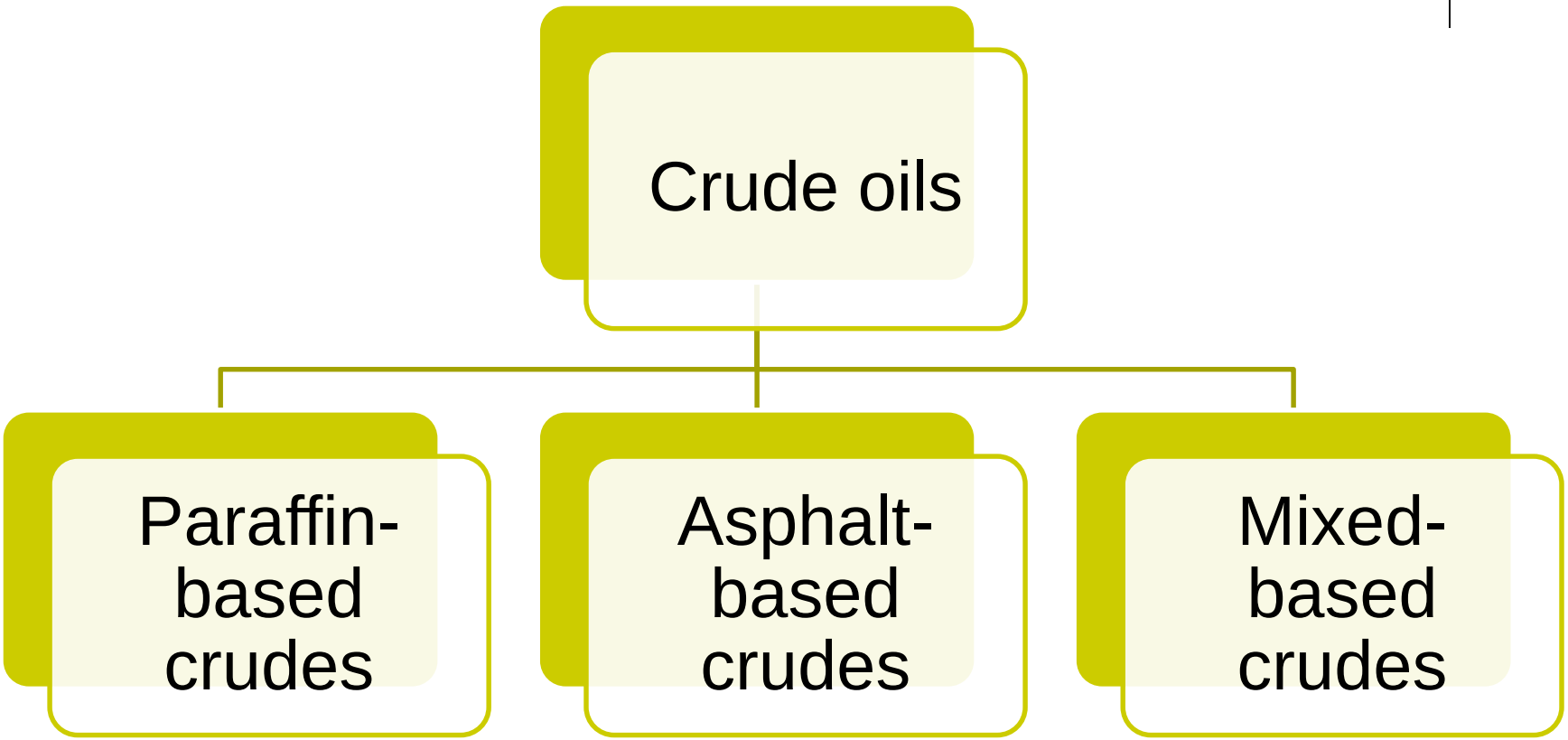
Fossil Fuels are *Finite Fuels* ie.They will run out in the future and cannot be *regenerated*

- **Oil**: This was formed by ***dead sea creatures*** falling to the sea-bed where they were subjected to chemical change by Bacteria

Coal: This was formed by the ***decay of Vegetation*** which was subjected to heat and pressure over a very long period of time

Gas was formed in much the same way as Oil.It is often collected when drilling for Oil.

Alternative sources of Energy which are **Renewable** must be found eg. ***Solar, Wind Tide and Wave Power***

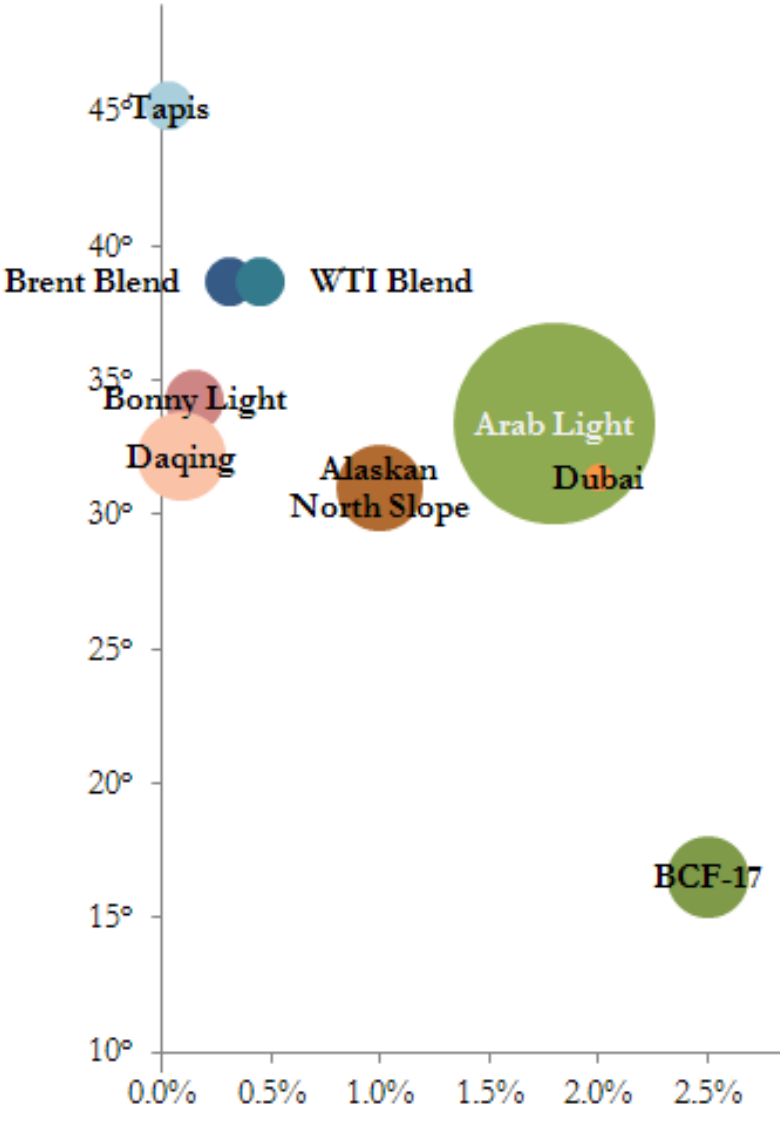

Crude oils
Paraffin-based crudes
Asphalt-based crudes
Mixed-based crudes

- Petroleum is a mixture of a very large number of different hydrocarbons; the most commonly found molecules are alkanes (paraffins), cycloalkanes (naphthenes), aromatic hydrocarbons, or more complicated chemicals like asphaltenes.
- Each petroleum variety has a unique mix of molecules, which define its physical and chemical properties, like color and viscosity.

Petroleum classification

- The petroleum industry generally classifies crude oil by the geographic location it is produced in (e.g. West Texas Intermediate, Brent, or Oman),

- The geographic location is important because it affects transportation costs to the refinery



Crude Oil Measurement

- The 42-gallon **barrel** ("**bbl**"), is about 159 liters.
- **Metric tonnes** ("**mt**"), one mt equals 2,204 lb 7.33 bbls/mt
- 1 BTU = 1.055 kJ.

1 Barrel of Crude Oil

42 gallons
10,000 B/D equals 500,000 tonnes/year (7.2 - 7.35 bbls per metric ton)
1 barrel #6 Oil = 6.287 Million BTU
300 lbs
6.33×10^9 Joules (6.33 Gigajoules)

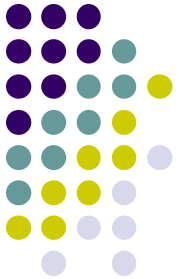
- Crude oil may be considered *light* if it has low density or *heavy* if it has high density;
  - *Light* crude oil is more desirable than *heavy* oil since it produces a higher yield of petrol,

- Its API gravity (an oil industry measure of density),

American Petroleum Institute : API

- Sulfur content. and it may be referred to as sweet if it contains relatively little sulfur or sour if it contains substantial amounts of sulfur.
  - while sweet oil commands a higher price than sour oil because it has fewer environmental problems and requires less refining to meet sulfur standards imposed on fuels in consuming countries.

Specific gravity



- Defined as: Density of oil at 60 ^{o}F / Density of water at 60 ^{o}F.
- Expressed as Sp.gr.(60/60^{o}F).

API gravity

American Petroleum Institute

- Related to the Sp. Gr. by the expression:
- $^{o}API = [141.5 / Sp.Gr.(60/60^{o}F)] – 131.5$
- Which ranges from 5 to 50, the higher the lighter.

API gravity formulas [edit]

The formula to calculate API gravity from Specific Gravity (SG) is:

$$\text{API gravity} = \frac{141.5}{\text{SG}} - 131.5$$

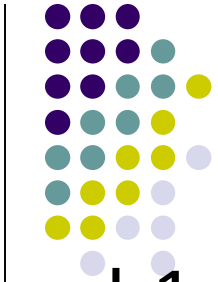
Conversely, the specific gravity of petroleum liquids can be derived from their API gravity value as

$$\text{SG at } 60^\circ\text{F} = \frac{141.5}{\text{API gravity} + 131.5}$$

Thus, a heavy oil with a specific gravity of 1.0 (i.e., with the same density as pure water at 60 °F) has an API gravity of:

$$\frac{141.5}{1.0} - 131.5 = 10.0^\circ\text{API}$$

Fuel Oil Classifications

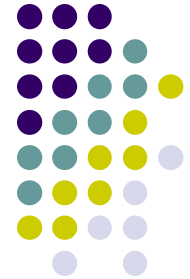


- Fuel oil is classified into 6 classes, numbered 1 through 6, according to its boiling point, composition and purpose.
- The boiling point, ranging from 175 to 600 °C, and carbon chain length, 20 to 70 atoms, of the fuel increases with fuel oil number.
- Viscosity also increases with number, and the heaviest oil has to be heated to get it to flow.
- Price usually decreases as the fuel number increases.

Fuel Oil Classifications

- No. 1 fuel oil, No. 2 fuel oil and No. 3 fuel oil are variously referred to as distillate fuel oils, diesel fuel oils, light fuel oils, gasoil or just distillate.
- For example, No. 2 fuel oil, No. 2 distillate and No. 2 diesel fuel oil are almost the same thing (diesel is different in that it also has a cetane number limit which describes the ignition quality of the fuel).
- Distillate fuel oils are distilled from crude oil.
- https://www.pei.org/wiki/fuel-oil

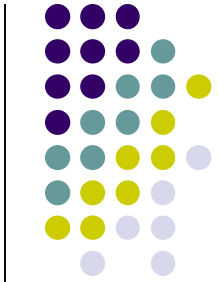
Oil grades



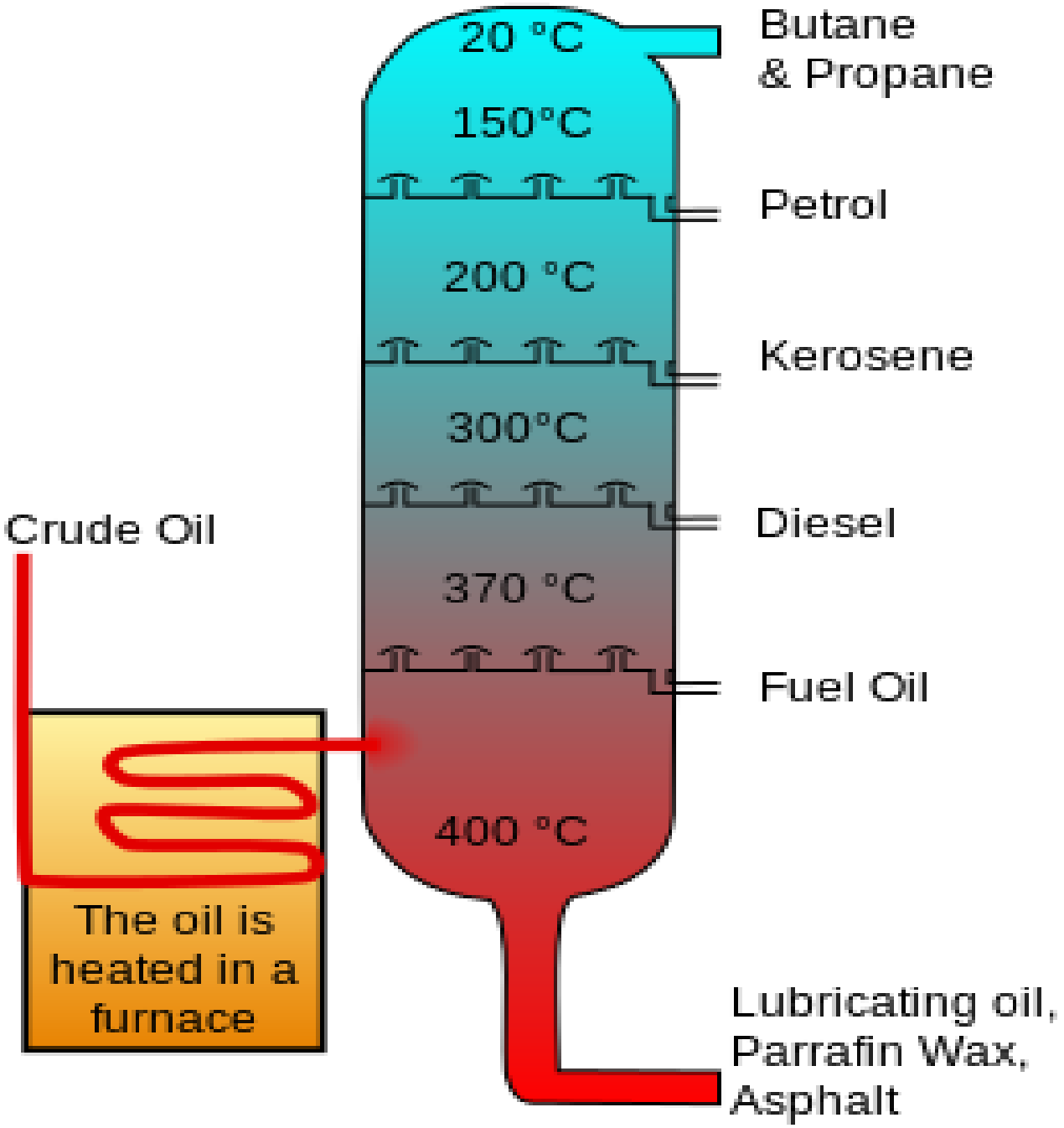
- There are six grades of commercial fuel oil;
- Fuel no. 1 is a distillated oil and is the lightest and least viscous, it is the same as kerosene and is used in vaporizing burners.
- Fuel no. 2 is a distillated oil and is generally used for domestic heating.
- Fuel no. 4 is relatively light, residual commercial grade heating oil that can be pumped without heating at moderate temperatures.

- Fuel oil no. 5 is a heavy, viscous, residual, commercial grade fuel oil.
- Fuel no. 6, “Bunker – c” oil is the heaviest and most viscous of the residual fuel oils.
- Both #5 and #6 require heating before they can be pumped.

Table of fuel oil grades and specifications



Oil Grade	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
API gravity	> 35	> 26	merged with no. 2			
Commercial name	Kerosene	Diesel		Fuel Oil	Fuel Oil	Bunker C
Sulfur content %	S< 0.5	S< 1.0				
Local Sulfur Content, %		S = 1.5				S = 4
Chain length	9-16	10-20		12-70	12-70	20-70

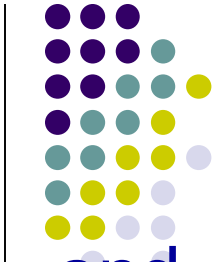

20 °C
Butane
& Propane
150°C
Petrol
200 °C
Kerosene
300°C
Diesel
Crude Oil
370 °C
Fuel Oil
400 °C
The oil is heated in a furnace
Lubricating oil, Parrafin Wax, Asphalt

Measurement Units and Conversion Factors

Depending on the purpose of the measurement-and on regional or national preferences - oil, gas, gas liquids and their products may be measured in terms of **volume**, **weight** or **thermal energy**. For example:

- Petroleum engineers measure oil and gas **volumes** to answer questions like, "How much oil or gas do I have in my reservoir? How much can be produced during the life of the field? What is the daily production rate?"
- In contrast, ship owners would want oil shipments to be measured in **weight** to avoid overloading their tankers.
- Marketers, on the other hand, are interested in the value of the products to their customers. When they sell oil and gas products for fuel, they charge on the basis of **thermal energy** units rather than volume or weight.

Oil Quality: API Gravity



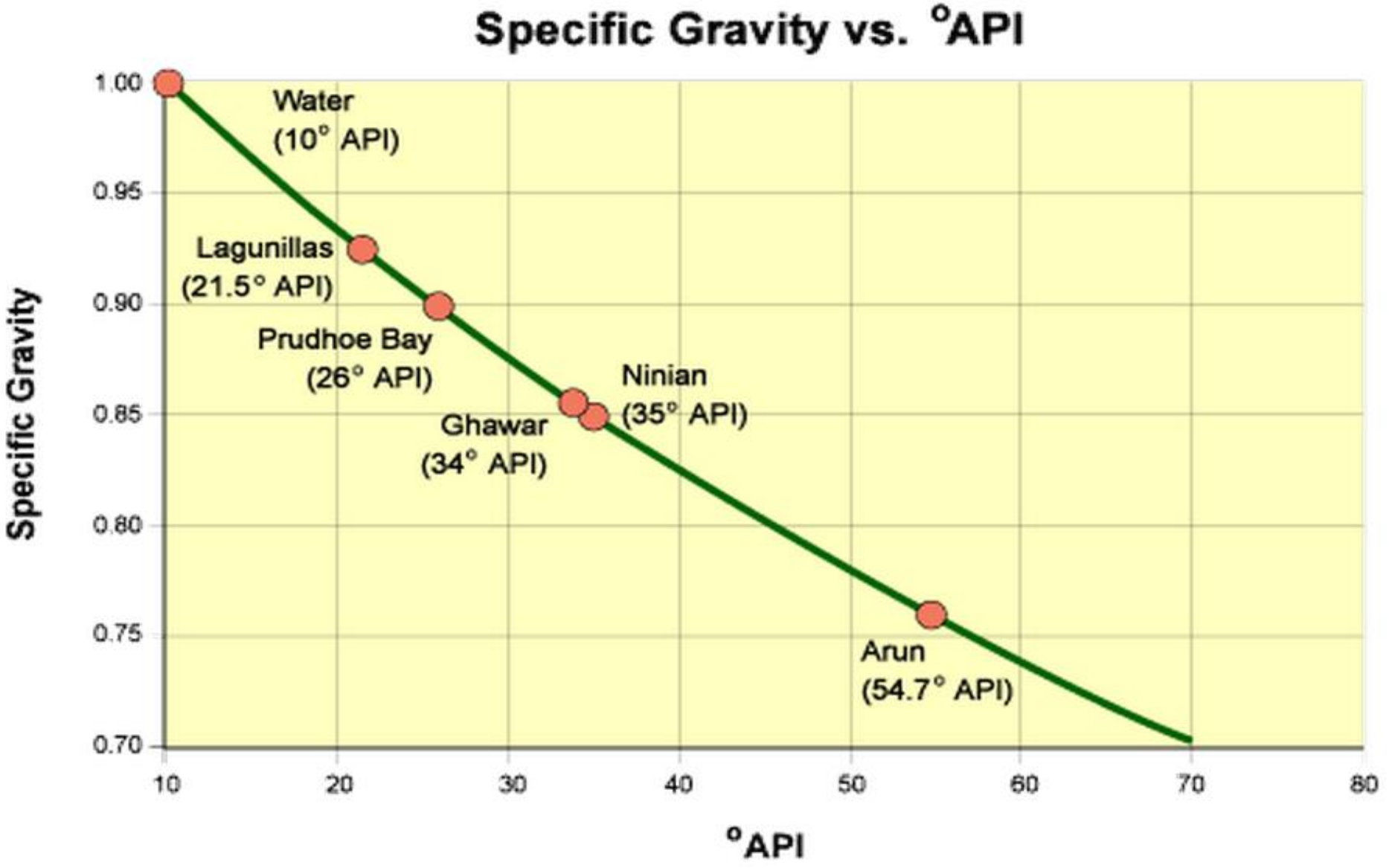
- lighter oils are generally easier to produce and refine than heavy oils, and therefore tend to have higher value.
- Oil density is sometimes expressed in terms of its **specific gravity**, but more often is given as **API gravity**.
- the specific gravity (S.G.) of a liquid is defined as the density of that liquid divided by the density of fresh water. Fresh water, by definition, has a specific gravity of 1.0.

The American Petroleum Institute (API) has developed a special measure that expresses oil density in terms of API gravity, or ºAPI. It is related to the specific gravity as follows:

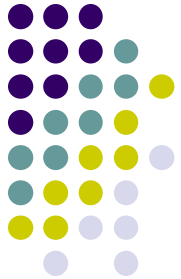
- **S.G. = 141.5/(131.5+ºAPI)**

or

- **ºAPI = (141.5/S.G.) - 131.5**


Specific Gravity vs. °API
Specific Gravity
1.00
0.95
0.90
0.85
0.80
0.75
0.70
10
20
30
40
50
60
70
80
°API
Water
(10° API)
Lagunillas
(21.5° API)
Prudhoe Bay
(26° API)
Ghawar
(34° API)
Ninian
(35° API)
Arun
(54.7° API)

Heating Value



- Usually, the HHV is reported because oil has a much less moisture content than coal.
- Heating value is related to API gravity through the following empirical Equation:

- $HHV = 17{,}645 + 54 \times {}^{o}API$, Btu/lb
- $HHV - LHV = 1032\ (M + 9H_2O)$, Btu/lb

Fig. 2.6 gives HHV, Sp. Gr., density and total heat of combustion in terms of API gravity for petroleum derivatives.

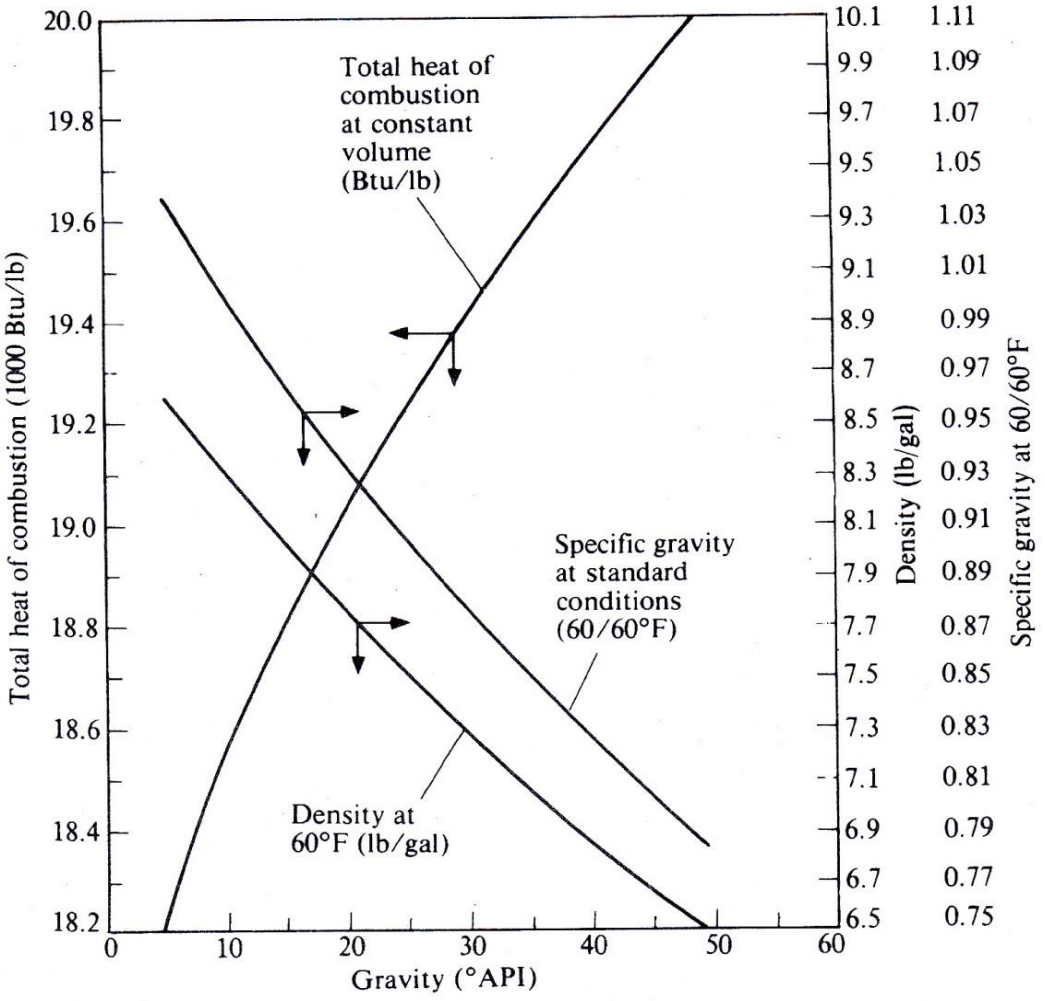


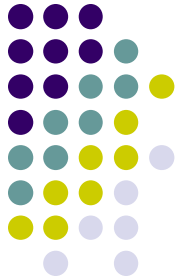
FIGURE 2.6
Properties of petroleum derivatives. (*From Steam: Its Generation and Use, 1972.*)

Flash point

- Minimum temperature at which the fuel vapor ignites. If the ignition flame is taken away, the flame goes off. (See App. G)

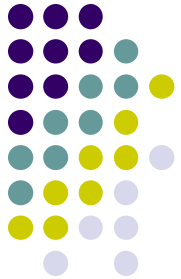
- **For example, For kerosene it equals 130 ºF (54.4 º C)**
- **For Diesel: 78- 80 º C**

Fire point



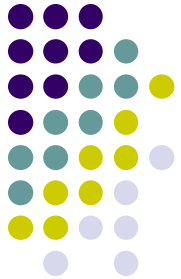
- Minimum temperature at which the fuel vapor burns.
- The flame is sustained even if the ignition flame is removed.
- **For example, For kerosene it equals78 - 80 ^{o}C**
- **For Diesel: 80 - 90 ^{o}C**

Pour Point



- Lowest temperature at which fuel will flow
- Indication of temperature at which fuel can be pumped.

Viscosity



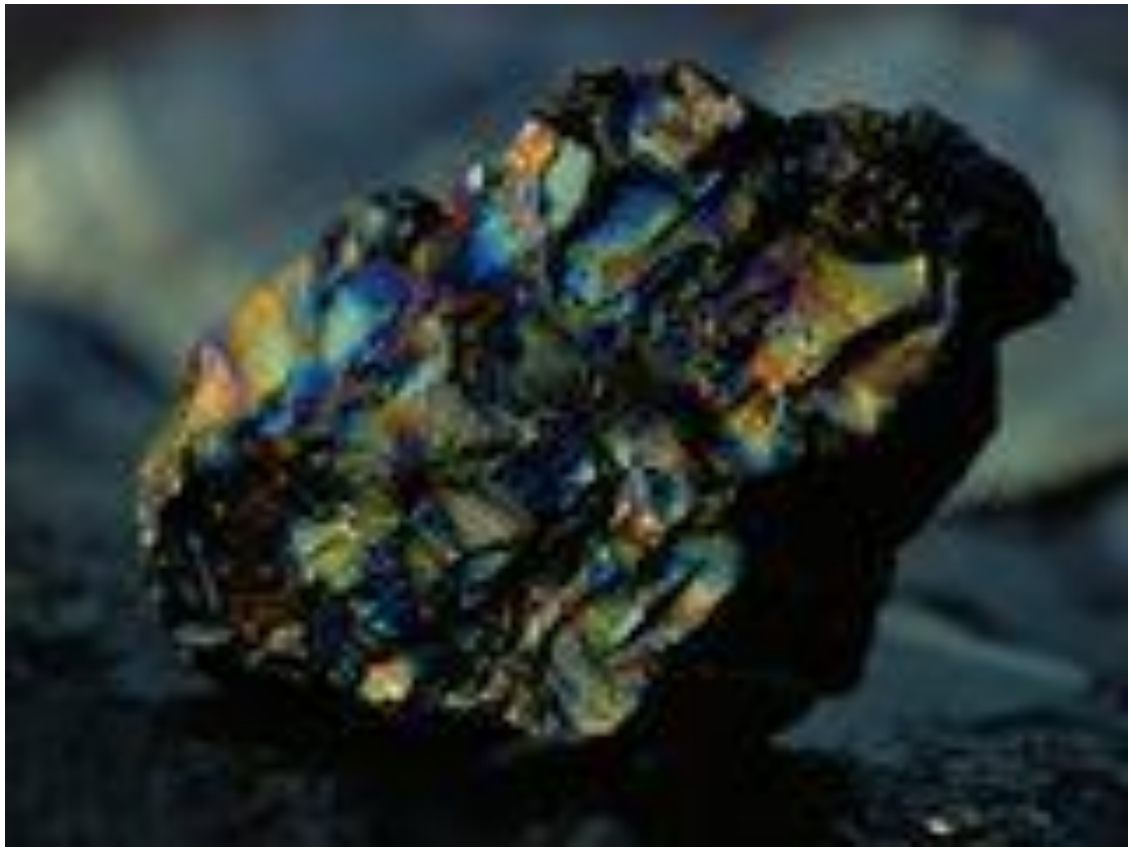
Measure of fuel's internal resistance to flow

- **Most important characteristic for storage and use**
- **Decreases as temperature increases**

COAL

Coal

- Coal is a sedimentary rock of vegetable origin, formed approximately 80 million years ago, were consolidated by pressure, heat and earth movement.



- It is estimated that at least 20 ft of compacted vegetation, in the absence of air and under the influence of pressure and temperature, is subsequently converted into peat "*low-grade fuel*" then into brown coal, then into lignite, then into subbituminous coal, then into bituminous coal and finally into anthracitic coal.

Coal

Coal currently provides 23% of the total U.S. energy needs.

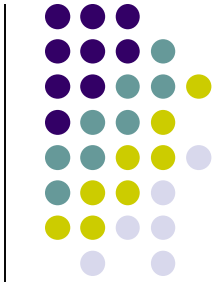
Now that oil and gas are dwindling, many energy producers and users are looking again at the potential of coal.

Formation of Coal Deposits

Unlike petroleum, coal is not formed from marine organisms, but from the remains of land plants.

A swampy setting, in which plant growth is lush and where there is water to cover fallen trees, dead leaves and other plant debris, is ideal for the initial stages to create coal.

Formation of Coal Deposits



The formation of coal from dead plant matter requires burial, pressure, heat and time.

The process works best under anaerobic conditions (***no oxygen***) since the reaction with oxygen during decay destroys the organic matter.

It is the carbon content of the coal that supplies most of its heating value.

The greater the carbon to oxygen ratio the harder the coal, the more reduced the state of the carbons and the more potential energy it contains.

Formation of Coal Deposits

The products of coalification are divided into four major categories based on the carbon content of the material.

Peat

Lignite

Bituminous

Anthracite

Peat

Peat is an accumulation of partially decayed vegetation matter and is the first stage in the formation of coal.

Peat forms in wetlands and bogs.

It contains a large amount of water and must be dried before use.

Historically, it has been used as a source of heat and burns with a long flame and considerable smoke.

Peat

Peat deposits are found in many places around the world, notably in Russia, Ireland, Finland, Scotland, Poland, northern Germany, the Netherlands and Scandinavia, and in North America .

Approximately 60% of the world's wetlands have peat

Peat

Peat is still mined as a fuel in Ireland and England

The peat is stacked to slowly dry out

Lignite

Lignite is the second step in the formation of coal and is formed when peat is subjected to increased vertical pressure from accumulating sediments.

Lignite, often referred to as brown coal, is the lowest rank of coal and used almost exclusively as fuel for steam-electric power generation.

It has a high inherent moisture content, sometimes as high as 66 percent, and very high ash content compared to bituminous coal.

Lignite

Because of its low energy density, brown coal is inefficient to transport and is not traded extensively on the world market compared to higher coal grades.

It is often burned in power stations constructed very close to the mines .

Bituminous

Bituminous Coal is the third stage of coal formation.

Additional pressure over time has made it compact and virtually all traces of plant life have disappeared.

It is of higher quality than lignite coal but of poorer quality than anthracite coal

It is greatly used in industry as a source of heat energy .

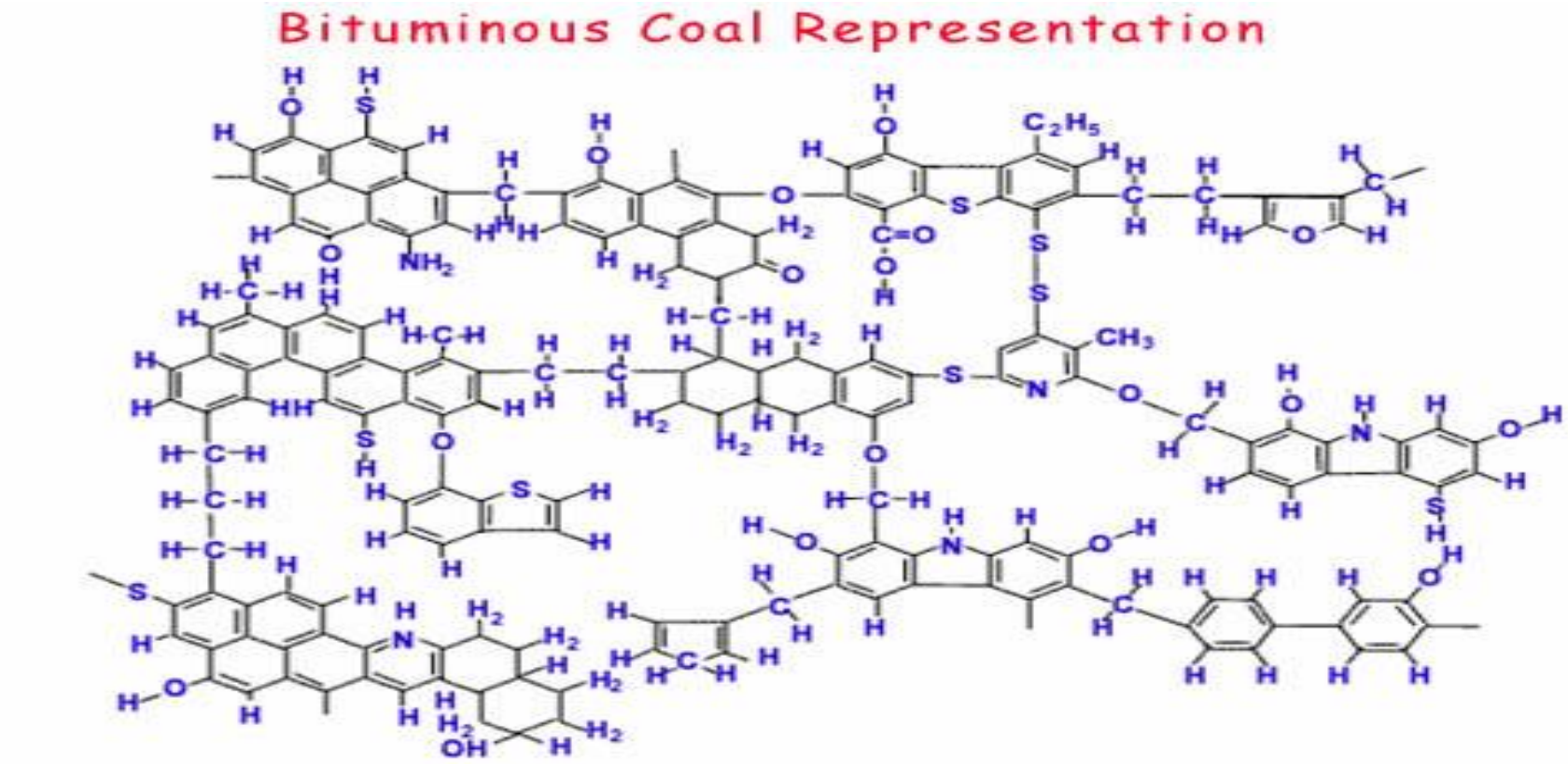
Bituminous

Bituminous coal is usually black, sometimes dark brown, often with well-defined bands of bright and dull material

It is a relatively hard coal containing a tar-like substance called bitumen

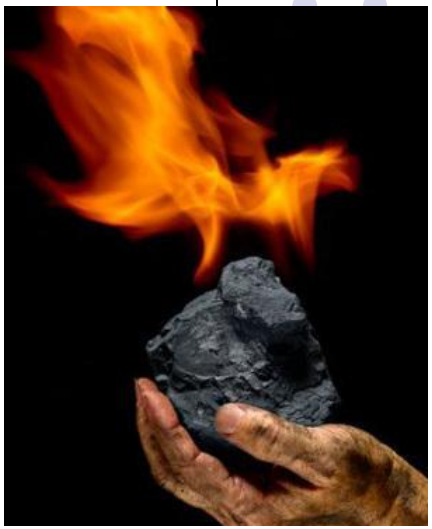
Bituminous

Bituminous coal is a complex molecular mix of 60-80% carbon, plus oxygen, hydrogen and nitrogen, plus some occasional impurities like sulfur



Coking Coal

When used for many industrial processes, bituminous coal must first be "coked" to remove volatile components.



Coking is achieved by heating the coal in the absence of oxygen, which drives off volatile hydrocarbons such as propane, benzene and other aromatic hydrocarbons, and some sulfur gases and a considerable amount of the contained water of the bituminous coal.

Coking coal is used in the manufacture of steel, where carbon must be as volatile-free and ash-free as possible.

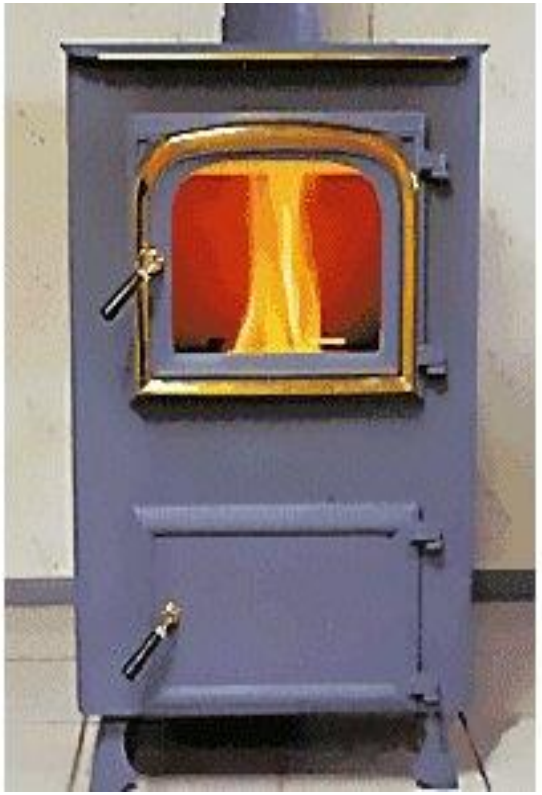
Anthracite

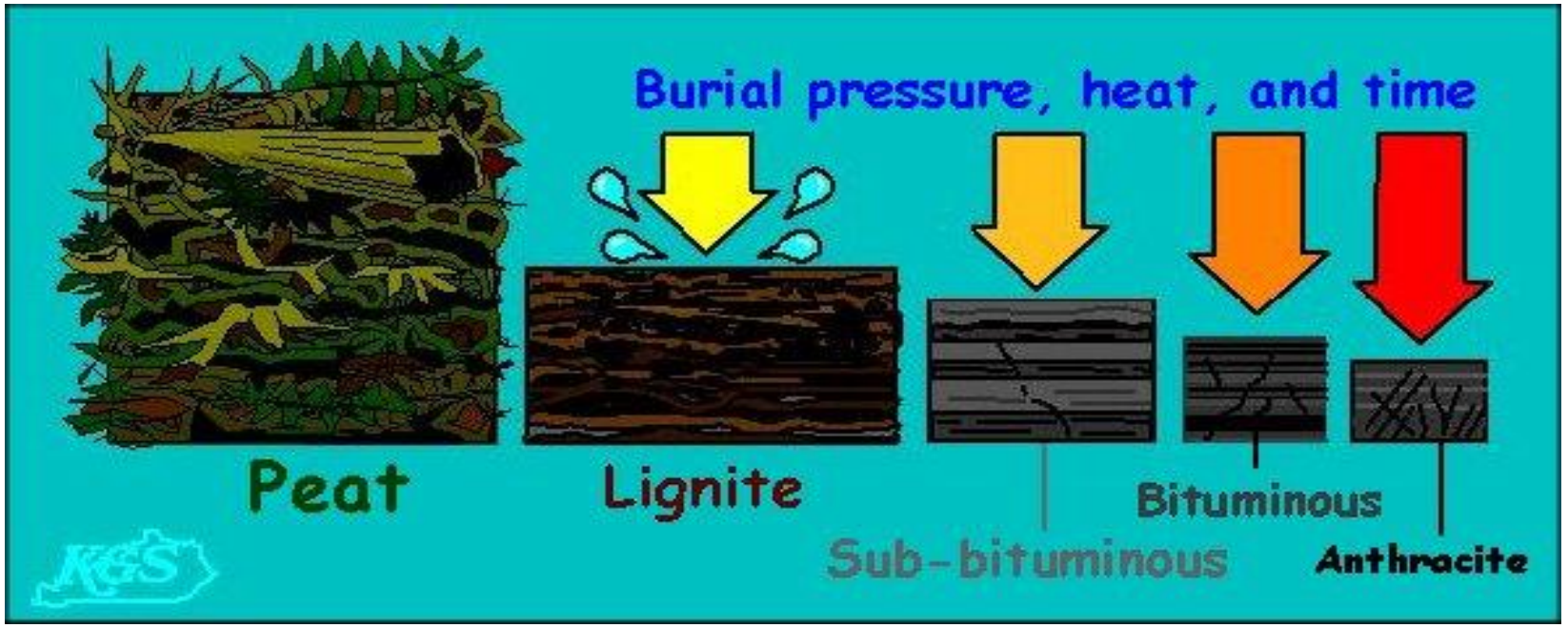
Anthracite is formed during the forth stage of coal formation.

It is the most valuable and highest grade of coal, and has a carbon content of 92-98%.

Physically, anthracite differs from bituminous coal by its greater hardness and higher density.

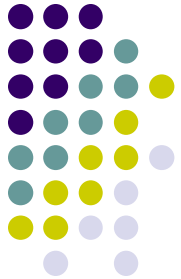
Plus, it burns far more efficiently with less smoke.





Peat — Increasing Rank — Anthracite

American Society for Testing Materials (ASTM) coal classification



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

Appendix D

APPENDIX
D

ASTM
COAL
CLASSIFICATION
SYSTEM
(SUMMARY OF
ASTM D 388)

DEFINITIONS

Percent, dry, mineral-matter-free fixed carbon = % dry, mm-free FC:

$$\%\ \text{dry, mm-free FC} = \frac{(\text{FC} - 0.15\text{S})(100)}{1 - \text{M} - 1.08\text{A} - 0.55\text{S}} = \text{D, mm} - \text{f FC}$$

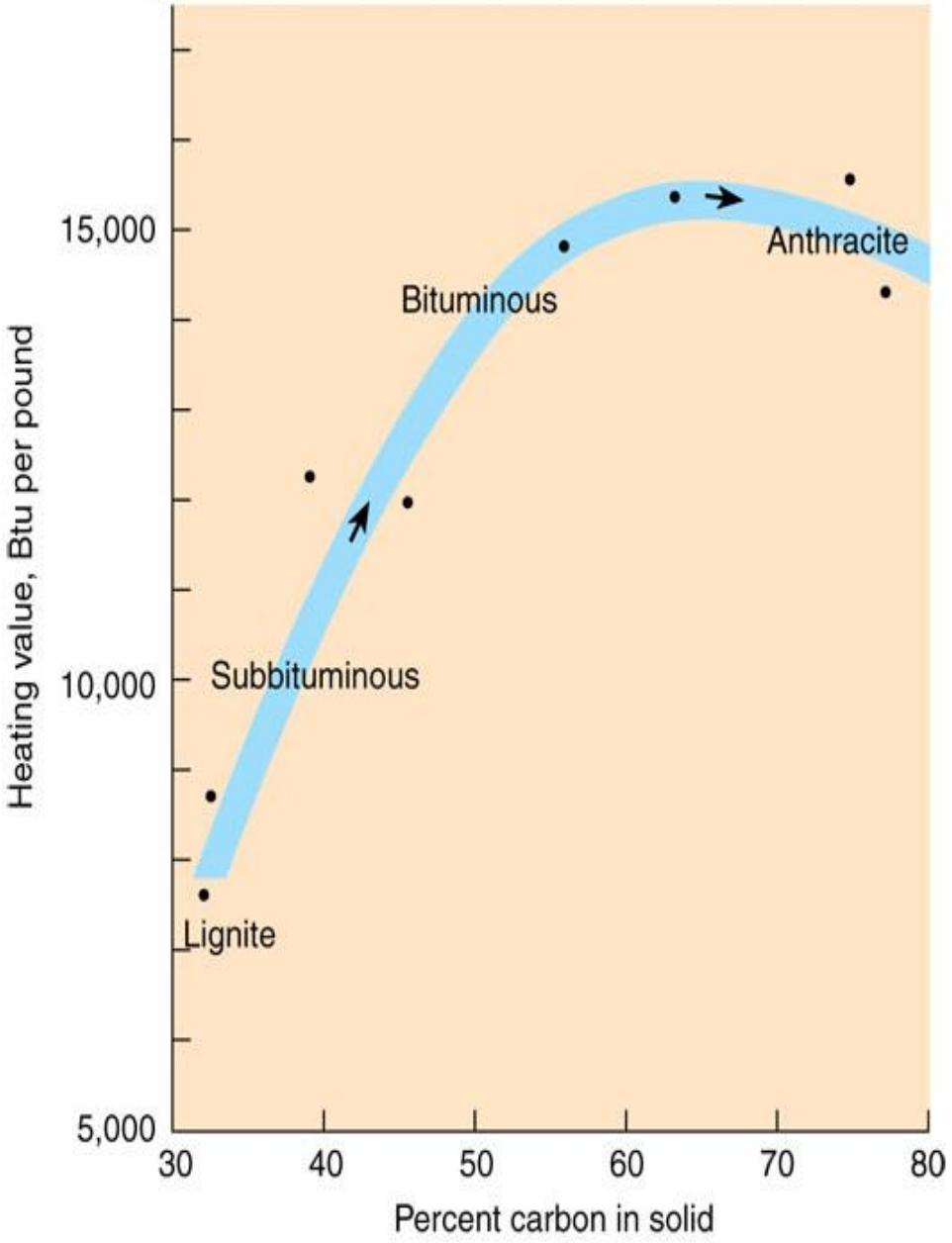
Moist, mineral-matter-free Btu content of coal, Btu/lbm = moist, mm-free Btu:

$$\text{Moist, mm-free Btu} = \frac{\text{Btu} - 0.55\text{S}}{1 - 1.08\text{A} - 0.55\text{S}} = \text{M, mm} - \text{f Btu}$$

COAL CLASSIFICATIONS

Class Group	Ranking parameter	Agglomerating character
Class I: Anthracitic coals		
Group 1. Metaanthracite	Dry, mm-free FC > 98%	Nonagg.
Group 2. Anthracite	98% > D, mm-f FC > 92%	Nonagg.
Group 3. Semianthracite	92% > D, mm-f FC > 86%	Nonagg.
Class II: Bituminous coals		
Group 1. Low-volatile bituminous	86% > D, mm-f FC > 78%	Usually agg.
Group 2. Medium-volatile bituminous	78% > D, mm-f FC > 69%	Usually agg.
	If dry, mm-free FC is less than 69%, rank coal according to the moist, mm-free Btu value	
Group 3. High-volatile A bituminous	M, mm-f Btu > 14,000	Usually agg.
Group 4. High-volatile B bituminous	13,000 < M, mm-f Btu < 14,000	Usually agg.
Group 5. High-volatile C bituminous	11,500 < M, mm-f Btu < 13,000	Usually agg.
	10,500 < M, mm-f Btu < 11,500	Agg.
Class III: Subbituminous coals		
Group 1. Subbituminous A	10,500 < M, mm-f Btu < 11,500	Nonagg.
Group 2. Subbituminous B	9,500 < M, mm-f Btu < 10,500	Nonagg.
Group 3. Subbituminous C	8,300 < M, mm-f Btu < 9,500	Nonagg.
Class IV: Lignitic coals		
Group 1. Lignite A	6300 < M, mm-f Btu < 8300	Nonagg.
Group 2. Lignite B	M, mm-f Btu < 6300 Btu/lbm	Nonagg.

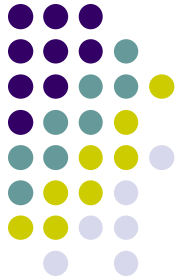
Fuel Efficiency



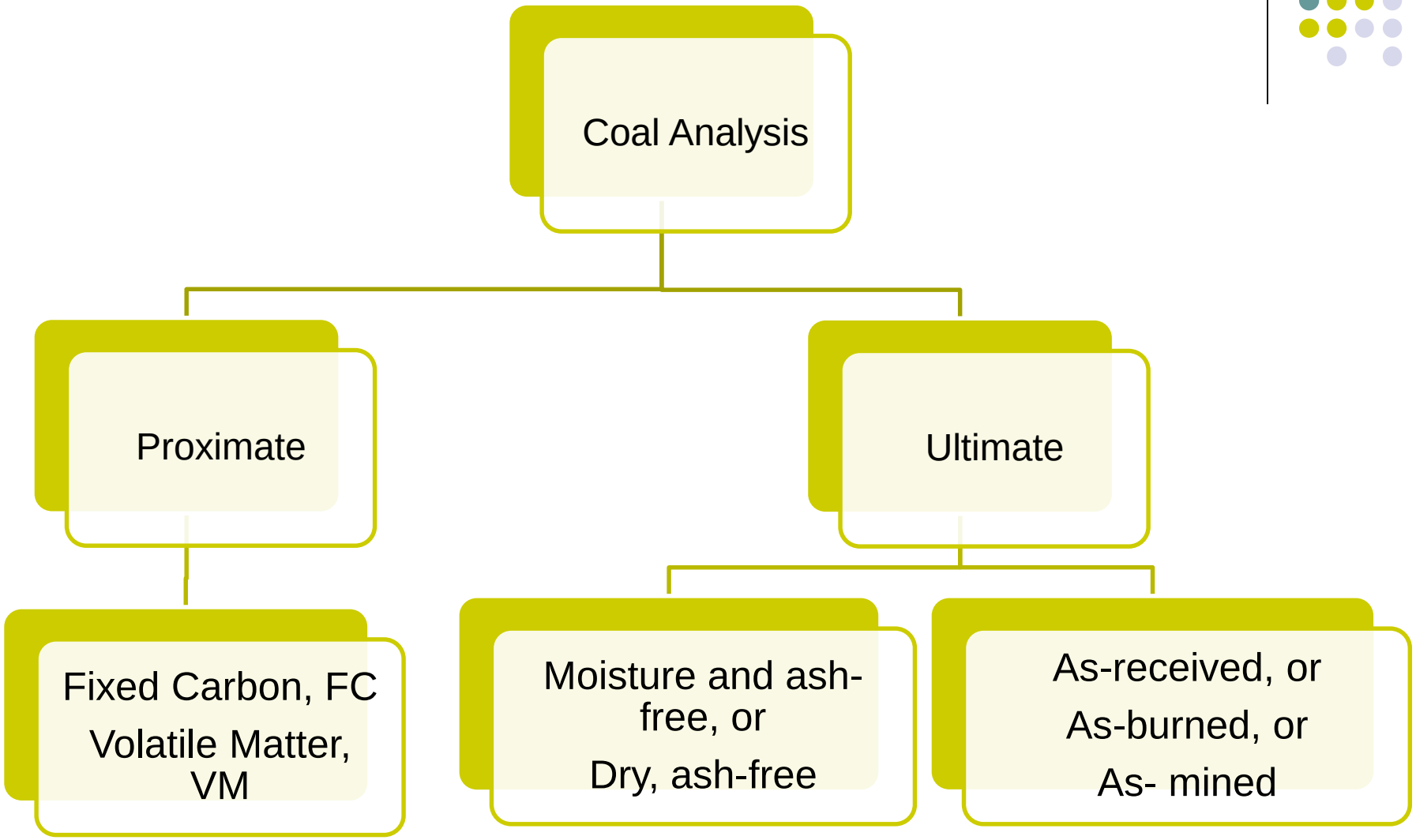
As the coals becomes harder, their carbon content increases, and so does the amount of heat released.

Anthracite produces twice the energy (BTUs) of lignite.

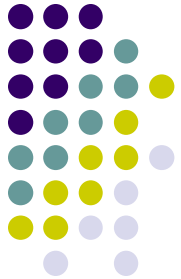
Coal Analysis



- As the rank of a coal increases, its carbon content increases from 75% to about 93% (by weight), the hydrogen content decreases from 6% to 3%, and the oxygen content decreases from 20% to 3%.


Coal Analysis
Proximate
Ultimate
Fixed Carbon, FC
Volatile Matter, VM
Moisture and ash-free, or
Dry, ash-free
As-received, or
As-burned, or
As- mined

1. Proximate analysis



- The "proximate" analysis gives:
  1. moisture content,
  2. volatile content, consisting of gases and vapors driven off during pyrolysis (when heated to 950 °C),
  3. the fixed carbon
  4. the ash, the inorganic residue remaining after combustion in the sample
  5. the high heating value (HHV) based on the complete combustion of the sample to carbon dioxide and liquid water.

Proximate analysis is the most often used analysis for characterizing coals in connection with their utilization.

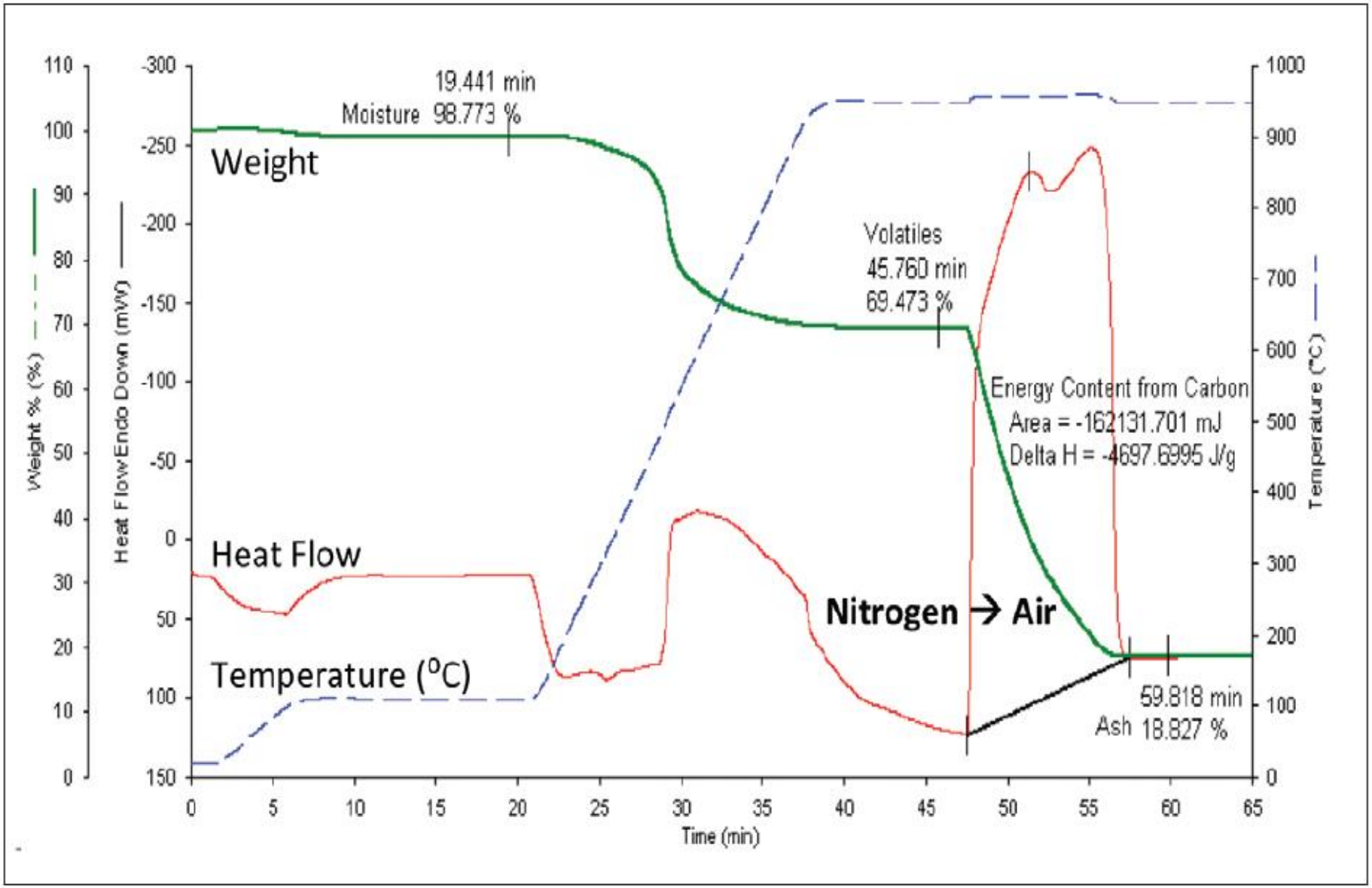


Figure 1. TGA Proximate analysis of coal using the STA 8000.

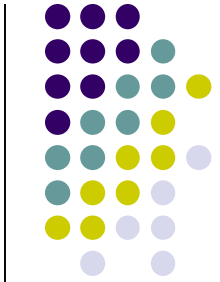
APPENDIX E

TYPICAL COAL ANALYSES

States and counties	Moisture and ash-free values								As received	
	VM	FC	C	H_2	O_2	N_2	S	kJ/kg†	*M*	*A*
ALABAMA										
Jefferson, Tuscaloosa	27.7	72.3	88.1	5.2	4.2	1.7	0.8	36,340	2–5	3–10
Jefferson, Tuscaloosa	32.9	67.1	86.7	5.3	5.0	1.8	1.2	35,875	2–5	2–10
Jefferson, St. Clair	35.4	64.6	85.2	5.4	5.8	1.8	1.8	35,470	2–5	4–12
Walker, Bibb, Shelby	38.0	62.0	84.3	5.4	7.6	1.7	1.0	35,120	1–5	2–14
ARKANSAS										
Sebastian, Logan	19.0	81.0	89.3	4.4	2.0	1.8	2.5	36,040	2–4	6–12
Franklin, Johnson	16.1	83.9	89.4	4.2	2.1	1.8	2.5	35,935	2–4	6–12
COLORADO										
Las Animas	36.5	63.5	84.9	5.5	7.4	1.5	0.7	35,525	1–7	6–20
Huerfano, Gunnison, Garfield	40.7	59.3	80.6	5.5	11.6	1.6	0.7	35,575	3–10	3–12
Weld, Boulder	42.5	57.5	75.0	5.1	17.9	1.5	0.5	30,085	17–30	3–6
Routt, Fremont	43.0	57.0	76.6	5.2	16.0	1.3	0.9	31,515	10–18	3–10
El Paso	46.4	53.6	71.5	5.0	21.8	1.1	0.6	28,095	20–35	5–14
ILLINOIS										
Franklin, Williamson	39.1	60.9	81.3	5.3	9.8	1.7	1.9	33,725	8–12	8–12
Saline, Perry	39.6	60.4	80.6	5.4	10.3	1.7	2.0	33,770	6–11	7–12
Macoupin, Sangamon	46.3	53.7	77.5	5.4	10.2	1.4	5.5	32,970	12–16	8–16
Madison, St. Clair	46.7	53.3	77.0	5.4	10.6	1.3	5.7	32,865	9–16	11–20
INDIANA										
Sullivan, Greene	45.2	54.8	80.9	5.6	9.7	1.8	2.0	33,725	10–14	6–12
Vigo, Vermillion, Knox	48.0	52.0	79.6	5.6	8.8	1.5	4.5	33,750	6–12	7–12

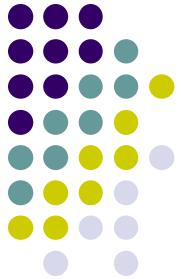
Composition of some typical solid fuels (% by mass)

Fuel	Carbon	Volatile matter	Moisture	Ash
Peat	44	65	20	4
Lignite	57	50	15	4
Bituminous Coal	82	25	2	5
Anthracite	90	4	1	3



- The moisture in coal is made up of two components: surface moisture and inherent moisture.
- The former is affected by the way in which the coal is stored, and is thus variable.

2. Ultimate analysis

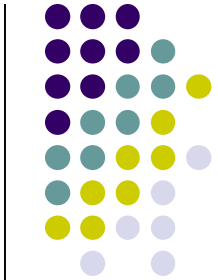


- Coals are also analyzed in terms of their elemental constituents, giving the ultimate analysis which was used earlier in stoichiometric calculations.
- Typical ultimate analyses of two types of solid fuels are given in Table 9.2 (next slide).

Table 9.2 Ultimate analyses (% by mass) of some coals

Coal	*Carbon*	*Hydrogen*	*Oxygen*	*Nitrogen*	*Sulfur*
Anthracite	94.4	2.9	0.9	1.1	0.7
Bituminous	89.3	5.0	3.4	1.5	0.8

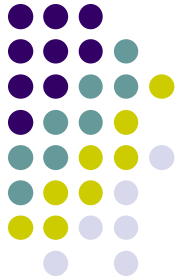
3. Coal Properties



- There are a number of properties which are important in identifying the suitability of a coal for any given application:

1. Size
2. Sulfur content
3. How coal burn
4. Weatherability
5. Grindability
6. Ash-softening temperature

1. Size

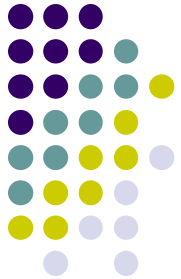


Some common size groups, together with their rather picturesque names, are given in Table (next slide).

Table 9.3 Size distribution for coals

Name	Upper limit (mm)	Lower limit (mm)
Large Cobbles	>150	75
Cobbles	100-150	50-100
Trebles	63-100	38-63
Doubles	38-63	25-38
Singles	25-38	13-18

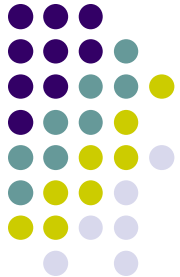
2. Sulfur Content



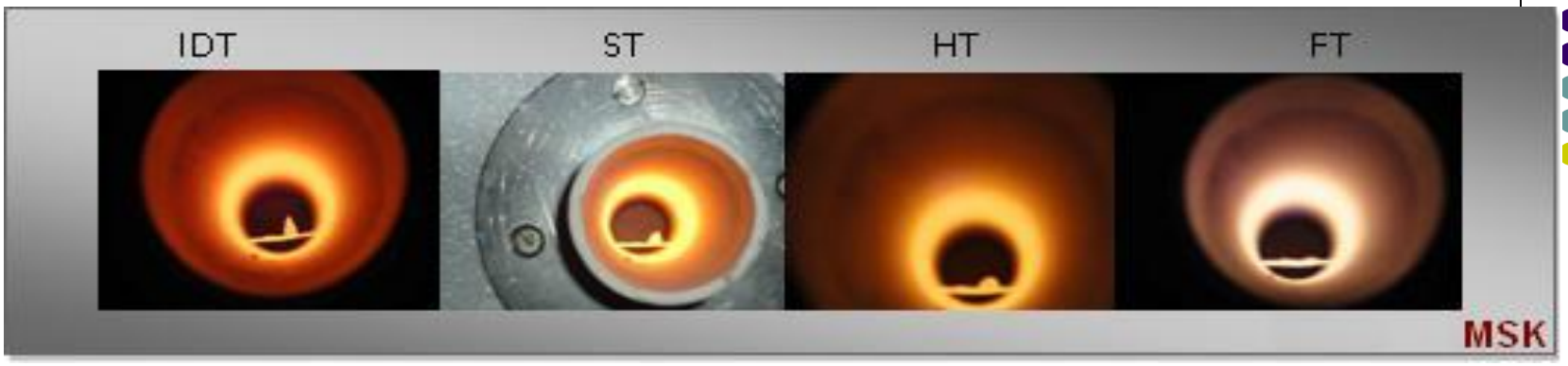
Many deep-mined coals have a fairly high sulfur content, typically around 1.5% by weight.

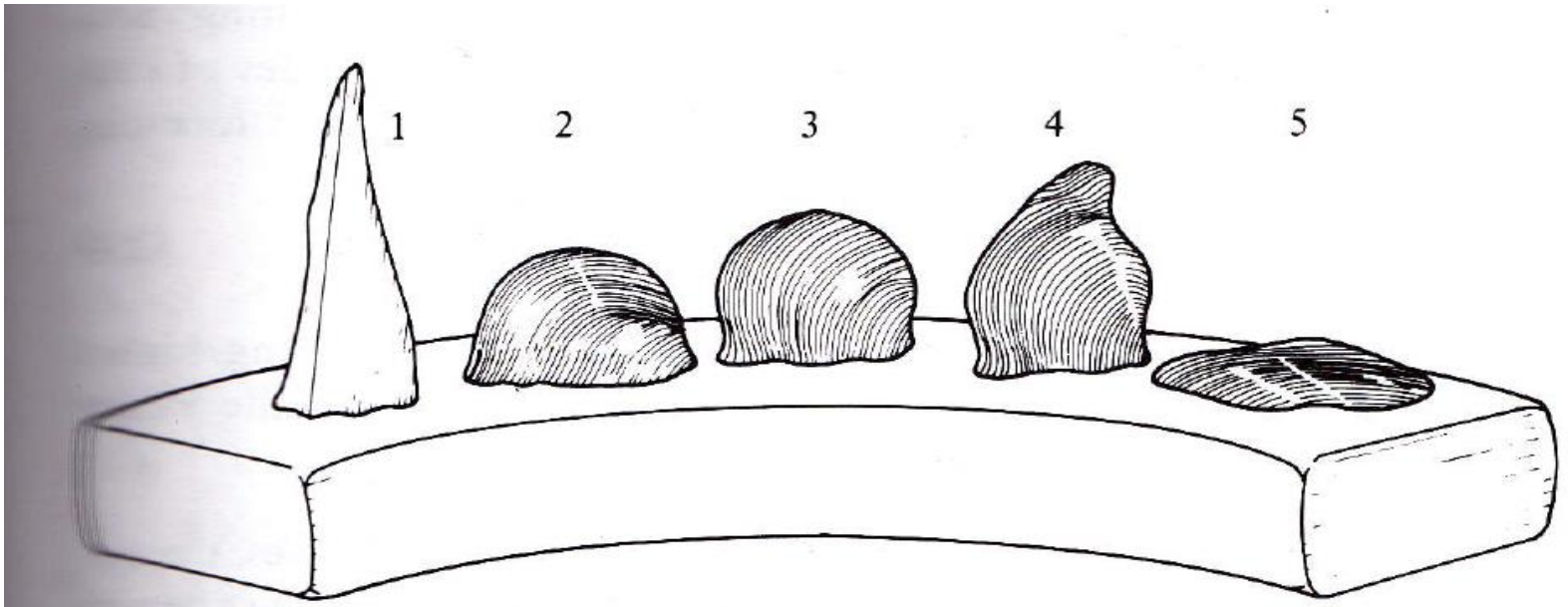
- **The same consideration apply to coal-fired installations as to oil-fired combustion equipment namely that condensation inside the plant must be avoided and that the design of the flue must ensure that ground concentration of sulfur oxides are controlled within acceptable limits.**

2. Ash Fusion Temperature



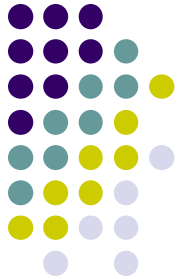
- **The melting point of the ash left after combustion of the coal is of particular importance in terms of the combustion and ash disposal equipment.**
- **If the ash fuses it produces a glassy, porous substance known as clinker (slag).**
- **The combustion equipment will be designed to handle either clinker or unfused ash, and use of the wrong type of coal can have dire consequences.**





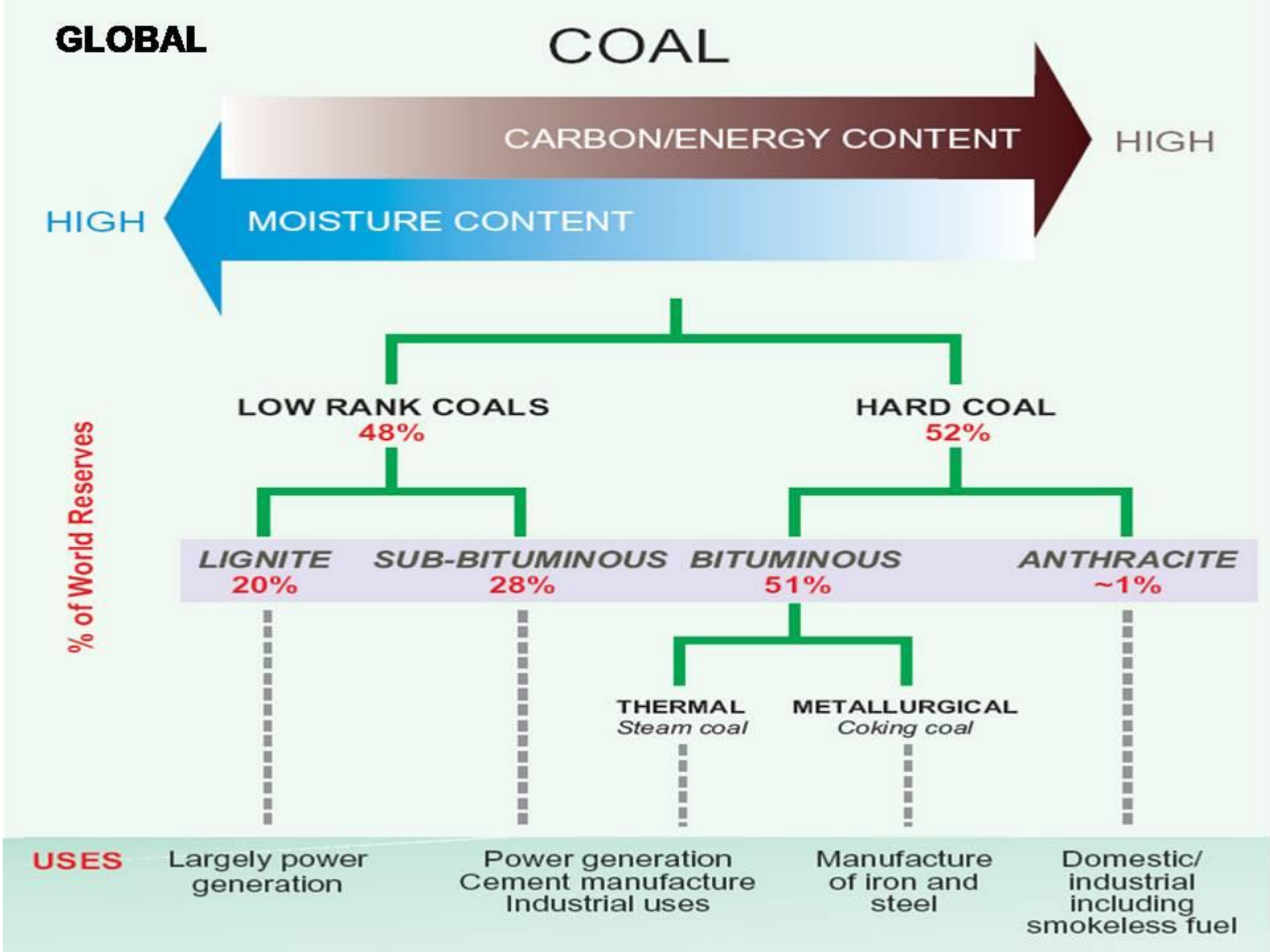
Cone 1, initial deformation temperature
Cones 2 and 3, softening temperature
Cone 4 has almost reached softening temperature
Cone 5, fluid temperature

6. Higher Heating Value (HHV)



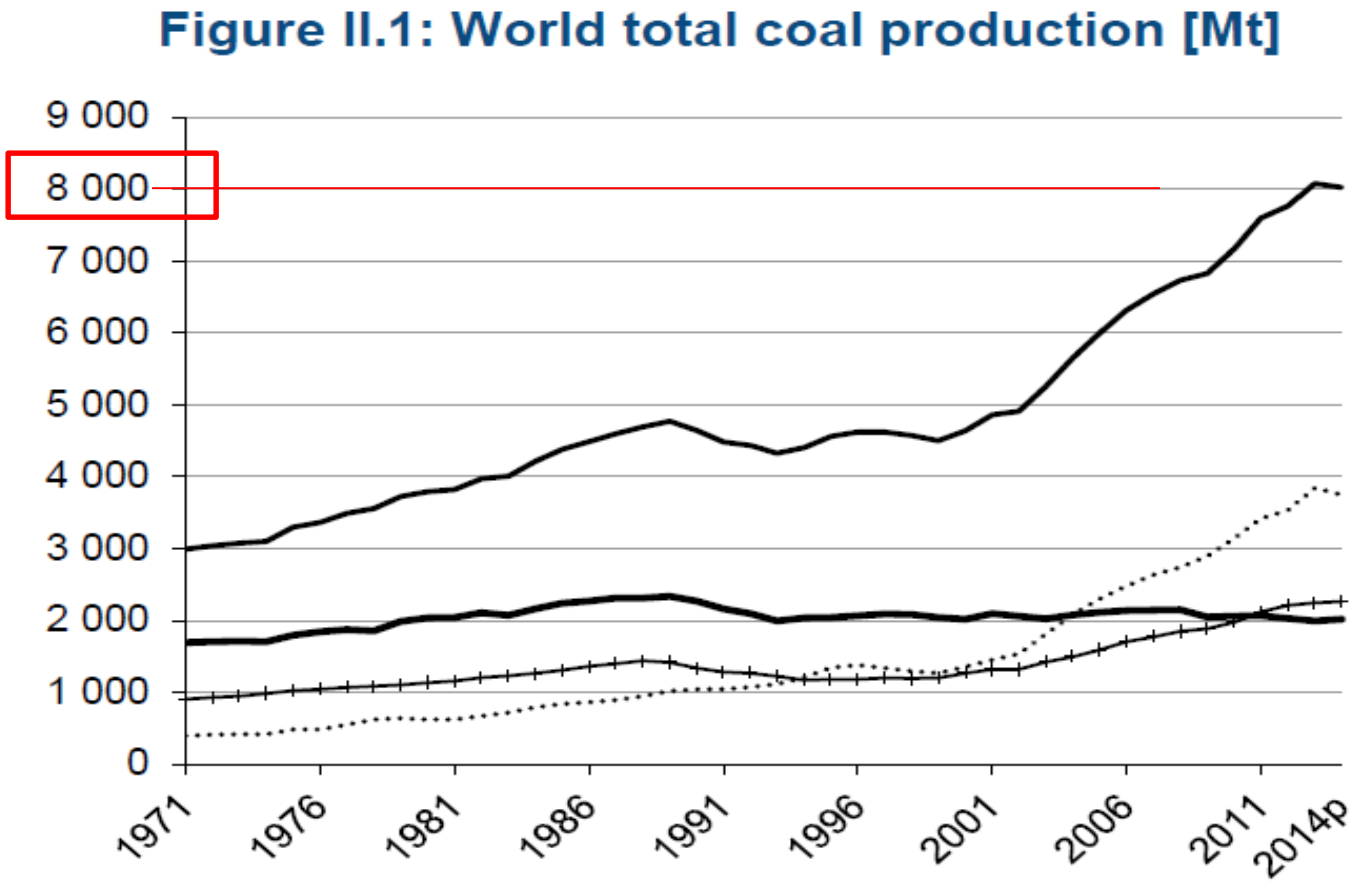
- **It is the energy obtained from burning a fuel if the combustion products are cooled down to the temperature at which water vapor coming out of the combustion condenses.**

- **Calorific value**
  The ranking of a coal is not necessarily related to its calorific value.
- **Coal fuels generally have a range of values from 21 to 33 MJ/kg (gross).**
- **The design rating of a coal-fired burner is usually based on an estimated calorific value of 26 MJ/kg (6,200 kcal/kg).**


GLOBAL
COAL
CARBON/ENERGY CONTENT
HIGH
HIGH
MOISTURE CONTENT
% of World Reserves
LOW RANK COALS
48%
HARD COAL
52%
LIGNITE
20%
SUB-BITUMINOUS
28%
BITUMINOUS
51%
ANTHRACITE
~1%
THERMAL
Steam coal
METALLURGICAL
Coking coal
USES
Largely power generation
Power generation
Cement manufacture
Industrial uses
Manufacture of iron and steel
Domestic/ industrial including smokeless fuel

- **Global coal consumption grew by 0.4% in 2014.**
- **Coal's share of global primary energy consumption fell to 30.0%.**

World Coal Market Review



8000 Mt of Coal in 2014

Total world coal production

- The People's Republic of China was once again the world's leading producer, as it has been since 1985 (Table II.2), with 3 747.5 Mt of total coal produced – a decline of 96.1 Mt from 2013.
- Other countries with notable declines in 2014 included Ukraine (-24.1 Mt), Indonesia (-16.9 Mt), and Serbia (-10.4 Mt). Declines in Ukraine were due to turmoil in the Eastern Oblasts of Donetsk and Luhansk in the second half of 2014, while declines in Indonesia were partly due to current weaker demand for Indonesian coals in China, and the potential for tighter regulations on imports in 2015, while production declines in Serbia were due to extensive flooding of mines.

Major coal producers

Table II.2: Major coal producers[(1)] [Mt]

	2012	2013	2014p
PR of China	3 532.5	3 843.6	3 747.5
United States	932.3	903.7	916.2
India	602.9	610.0	668.4
Australia	430.8	458.9	491.2
Indonesia	444.5	487.7	470.8
Russian Federation	329.4	326.0	334.1
South Africa	258.6	256.3	253.2
Germany	197.0	191.0	186.5
Poland	144.1	142.9	137.1
Kazakhstan	120.5	119.6	115.5
Colombia	89.0	85.5	88.6
Canada	66.5	68.9	69.0
Turkey	71.5	60.4	64.1e
Greece	63.0	53.9	48.0
Czech Republic	55.9	49.1	46.9
Ukraine	67.7	68.8	44.7
Other	*358.0*	*349.2*	*340.8*
World	**7 763.9**	**8 075.5**	**8 022.5**

Major coal exporters

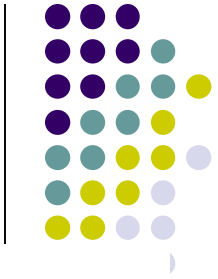


Table II.8: Major coal exporters [Mt]

	2012	2013	2014p
Indonesia	387.4	427.9	410.9
Australia	301.5	336.1	375.0
Russian Federation	131.7	140.8	155.5
United States	114.1	106.7	88.3
Colombia	83.3	80.2	80.3
South Africa	76.0	74.6	76.4
Netherlands	13.7	31.9	38.7
Canada	34.8	39.1	34.5
Kazakhstan	32.7	33.8	28.9
Mongolia	20.9	18.4	19.3
DPR of Korea	12.0	16.7	15.6
Viet Nam	15.2	12.8	9.9
Other	*51.2*	*55.7*	*50.3*
World	**1 274.5**	**1374.7**	**1 383.6**

Where is CHINA? #15 , 5.6 Mt

Major coal importers

Table II.9: Major coal importers [Mt]

	2012	2013	2014p
PR of China	288.8	327.2	291.6
India	164.2	188.8	239.4
Japan	183.9	195.6	187.7
Korea	124.3	126.5	130.9
Chinese Taipei	64.6	66.0	67.1
Germany	49.0	54.3	57.0
Netherlands	24.4	46.7	54.7
United Kingdom	44.8	49.4	40.6
Turkey	29.2	26.6	29.8
Russian Federation	30.3	29.4	25.3
Malaysia	22.6	22.1	23.6
Thailand	18.6	18.7	20.9
Brazil	16.5	18.0	20.4
Italy	24.5	20.1	19.9
Spain	22.4	13.7	16.4
Philippines	11.7	14.2	15.2
Other	*178.2*	*174.4*	*183.1*

Total coal consumption- OECD countries

Table II.15: Total coal consumption [Mtce] (selected countries)

	2012	2013	2014p
OECD Countries			
United States	606.9	618.2	615.8
Japan	160.9	172.4	165.3
Korea	109.8	110.9	115.4
Germany	112.3	114.3	109.4
Poland	79.1	82.2	77.5
Australia	67.1	65.8	62.7
Turkey	49.6	46.1	51.4e
United Kingdom	55.8	52.7	42.2
Canada	27.2	24.4	27.0
Czech Republic	24.3	22.9	23.2
Italy	22.7	18.8	17.8
Spain	21.8	15.7	16.6
Mexico	13.0	17.5	15.8
Netherlands	11.4	11.5	12.9
France	15.7	17.1	12.6
Chile	8.7	9.5	10.0
Greece	11.6	10.0	8.6
Slovak Republic	4.9	4.8	4.6
Other OECD countries	*34.5*	*35.3*	*32.2*

Total coal consumption- Non-OECD countries

Table II.15: Total coal consumption [Mtce] (selected countries)

	2012	2013	2014p
Non-OECD Countries			
PR of China	2 690.2	2 920.1	2 836.0
India	452.5	483.8	550.5
Russian Federation	169.7	156.5	149.5
South Africa	138.5	136.3	132.7
Chinese Taipei	56.4	57.6	58.9
Kazakhstan	53.4	52.9	54.4
Ukraine	62.4	60.5	48.4
Indonesia	42.9	45.0	46.7
Thailand	23.4	24.6	26.3
Brazil	19.9	21.6	24.6
Viet Nam	22.6	22.4	24.5
Malaysia	22.6	21.9	23.7
DPR of Korea	15.8	16.0	16.2
Philippines	12.4	15.4	15.8
Hong Kong (China)	10.9	11.4	12.1