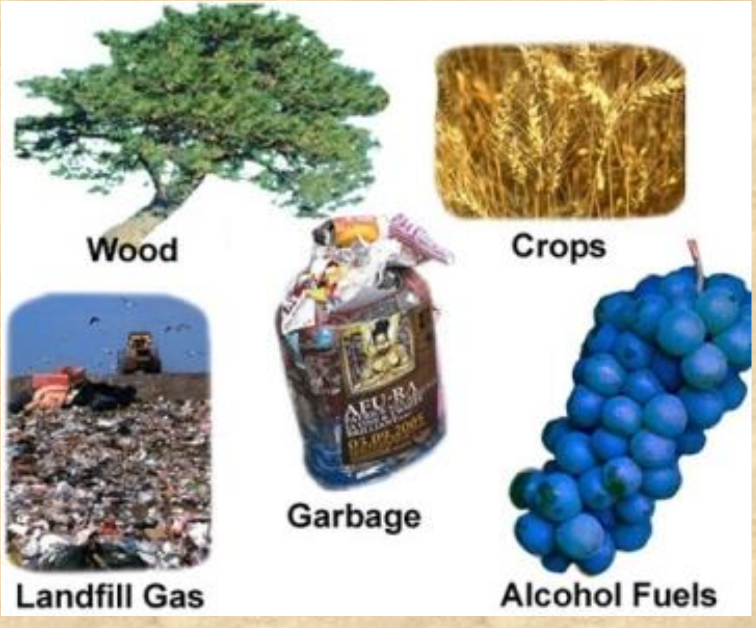
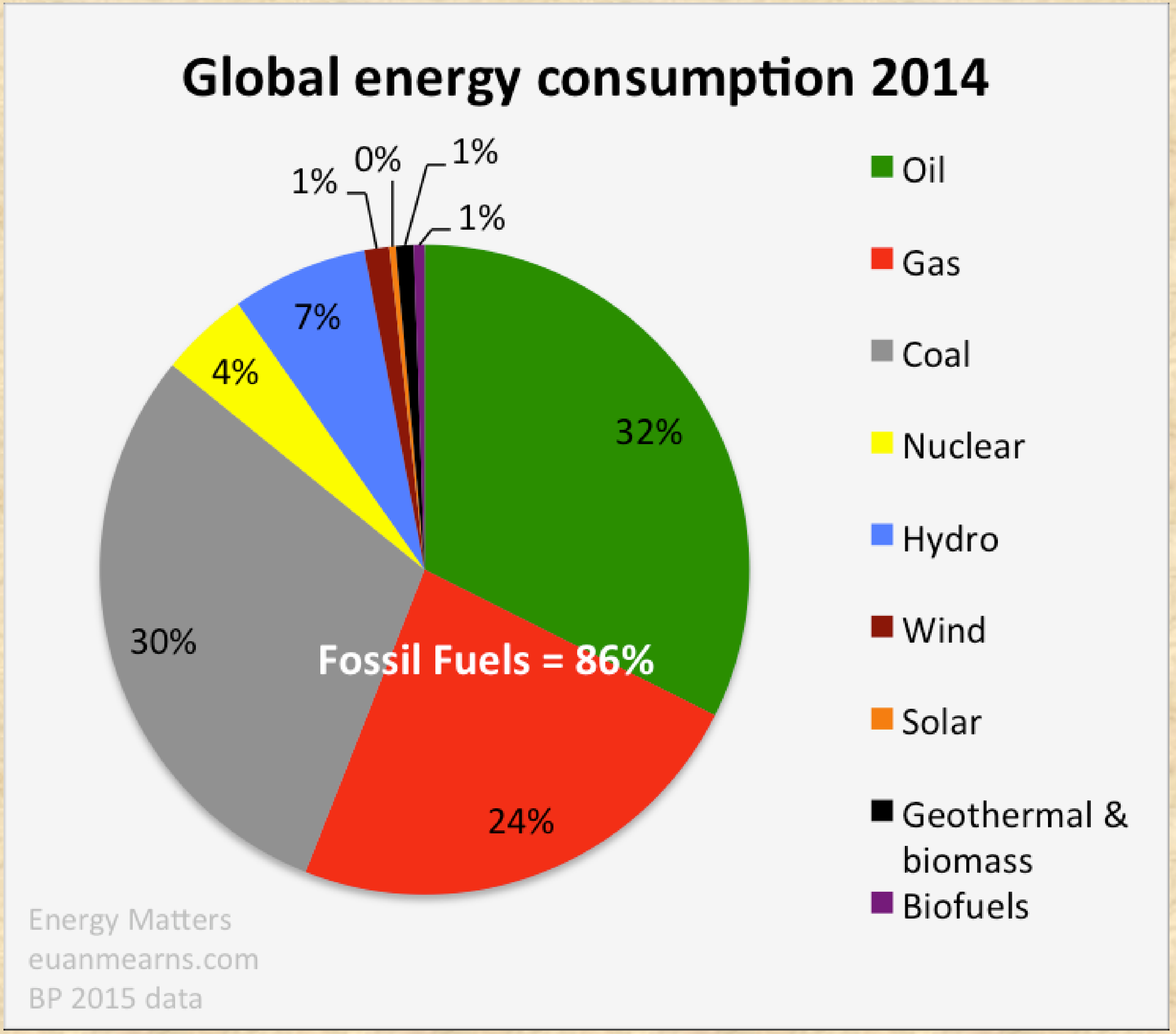
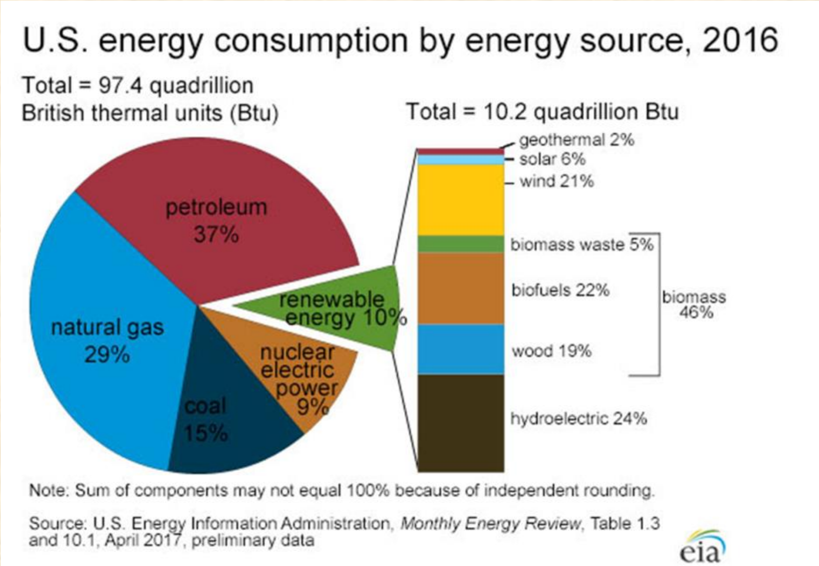
Fossil, Biomass, and Synthetic Fuels



Why do we care about heat engines?



Waste heat



U. S. electricity generation = 1.3×10^{19} J/y

Assuming 40% efficiency = 8×10^{18} J/y waste heat

Volume Lake Superior = 12,100 km^3

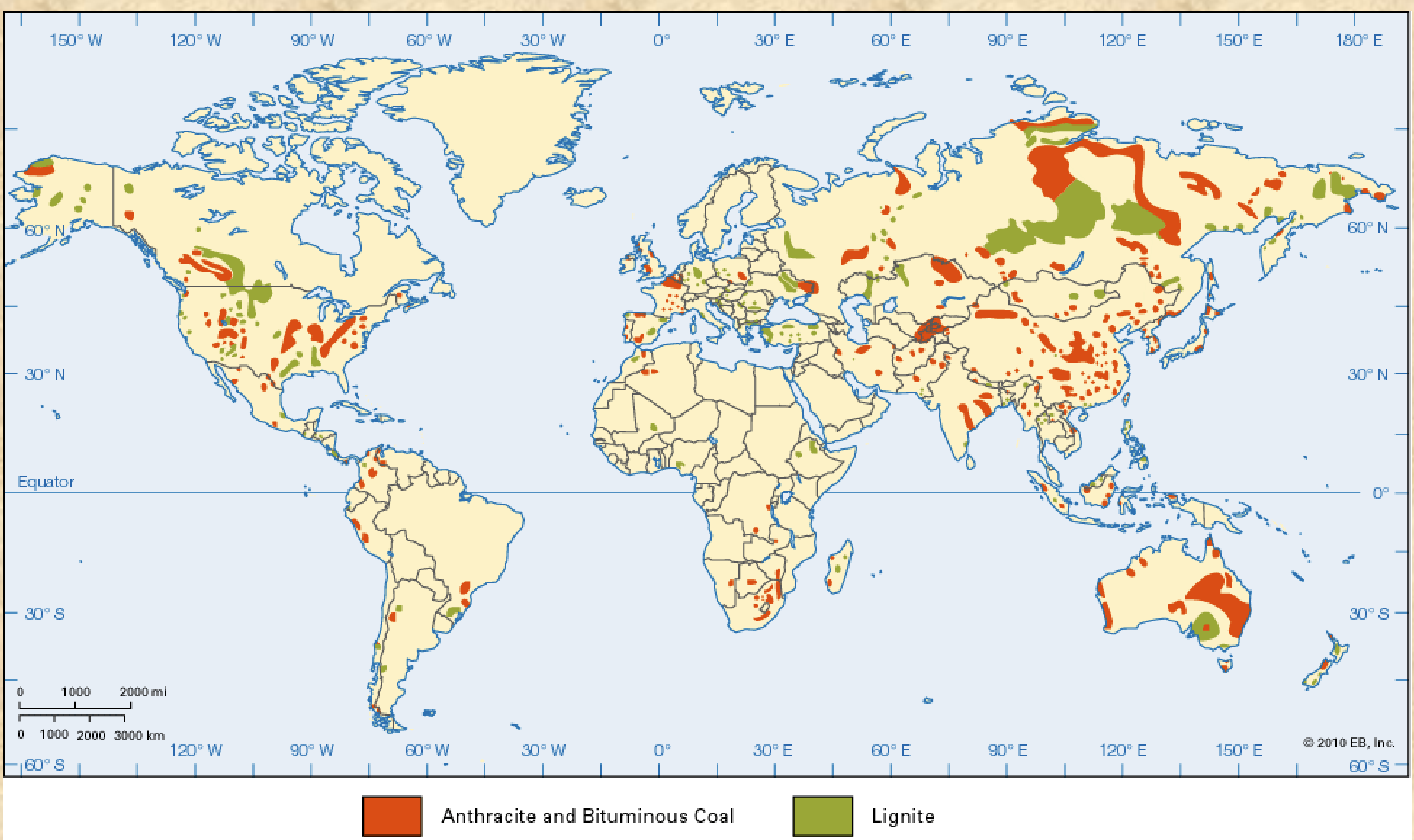
$T = \Delta H/cm = 8 \times 10^{18}/(1.2 \times 10^{16})(4.2 \times 10^{3})$

$= 0.16\ ^{o}C$

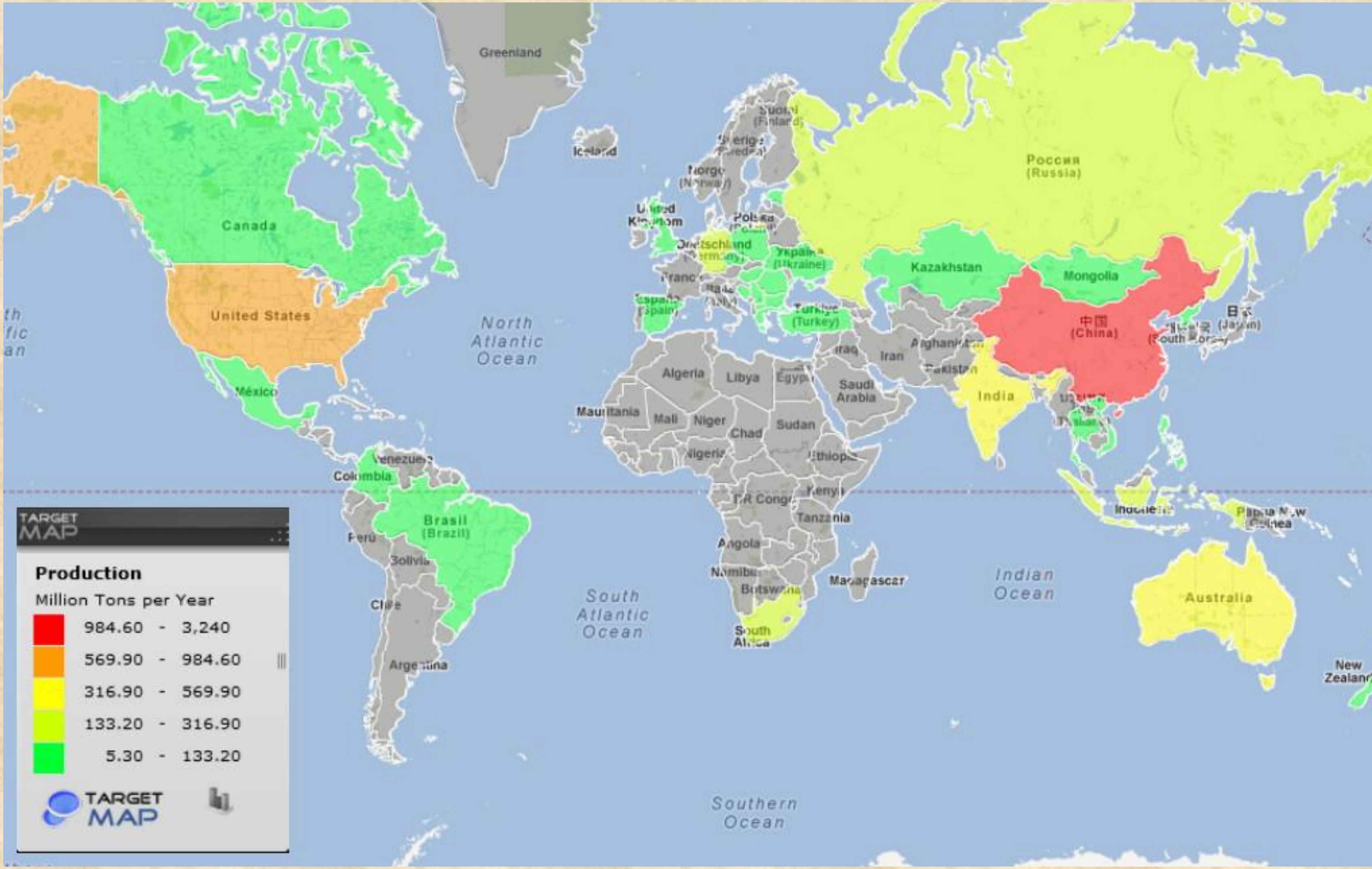
Fuel (Thermal) Efficiencies of Current Power Technologies

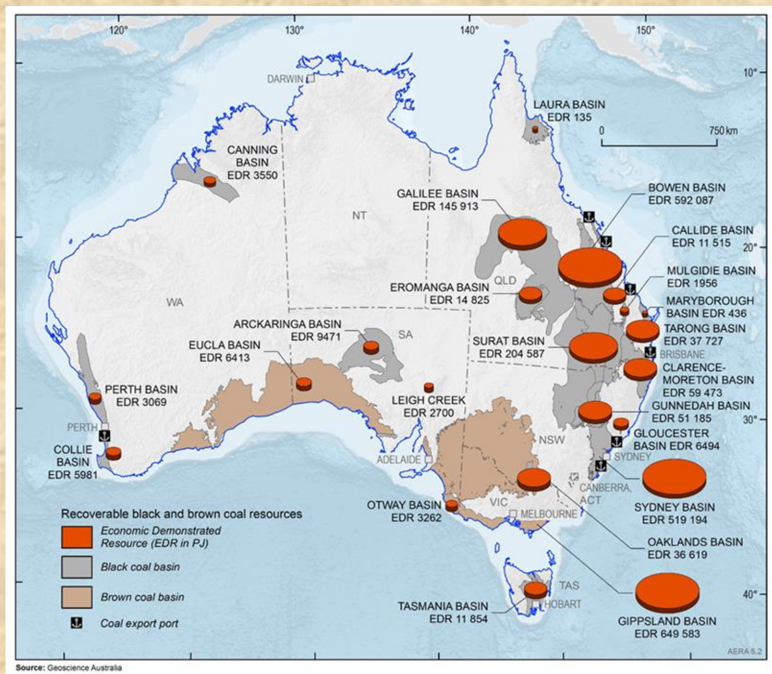
Type	Efficiency (%)
Steam electric power plant	
Steam at 62 bar, 480^{o}C	30
Steam at 310 bar, 560^{o}C	42
Nuclear Power plant	
Steam at 70 bar, 286^{o}C	33
Automotive gasoline engine	25
Automotive diesel engine	35
Gas turbine electric power plant	30
Combined cycle electric power plant	43
Fuel cell electric power	45

Location of World Coal Reserves

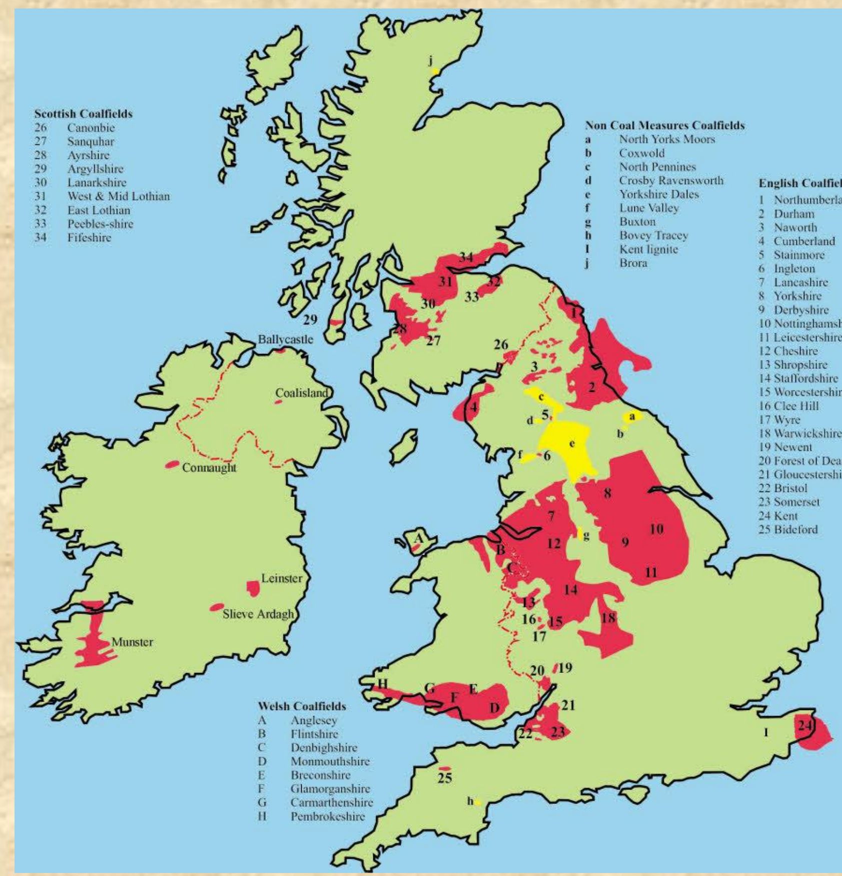


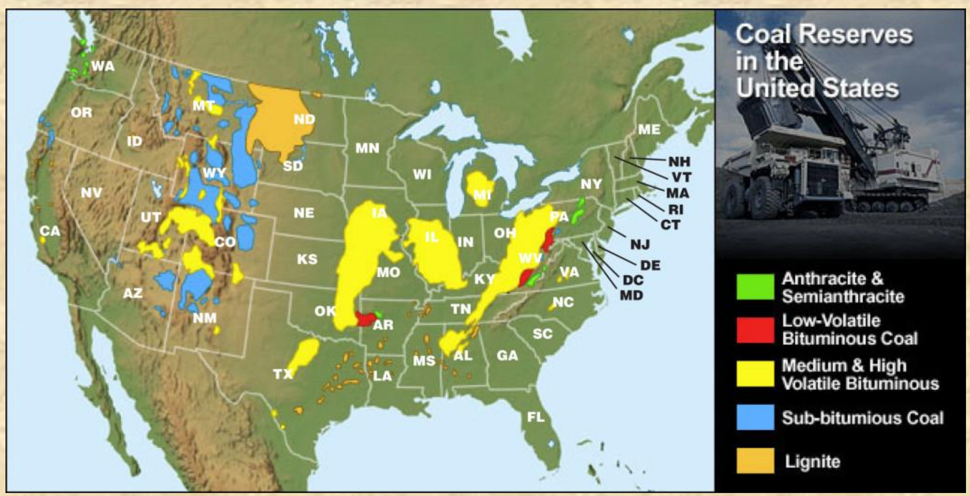
World Coal Production





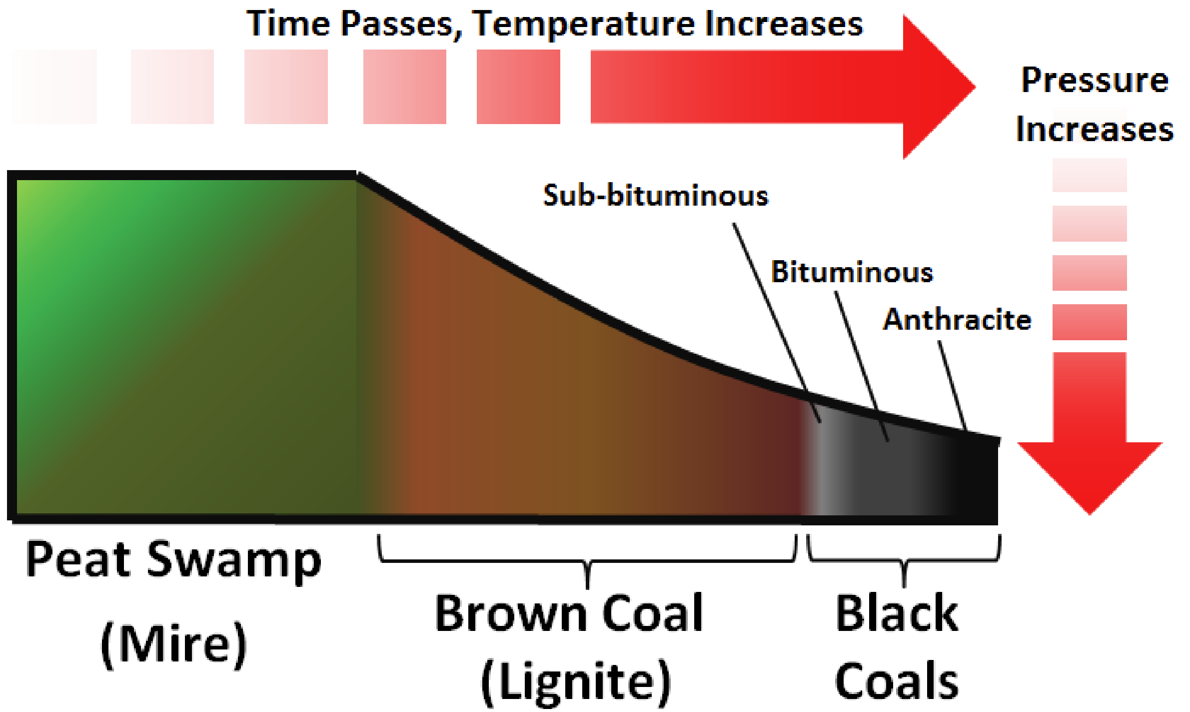
Coal reserves for select countries. Relationship between industrialization, politics, and coal.

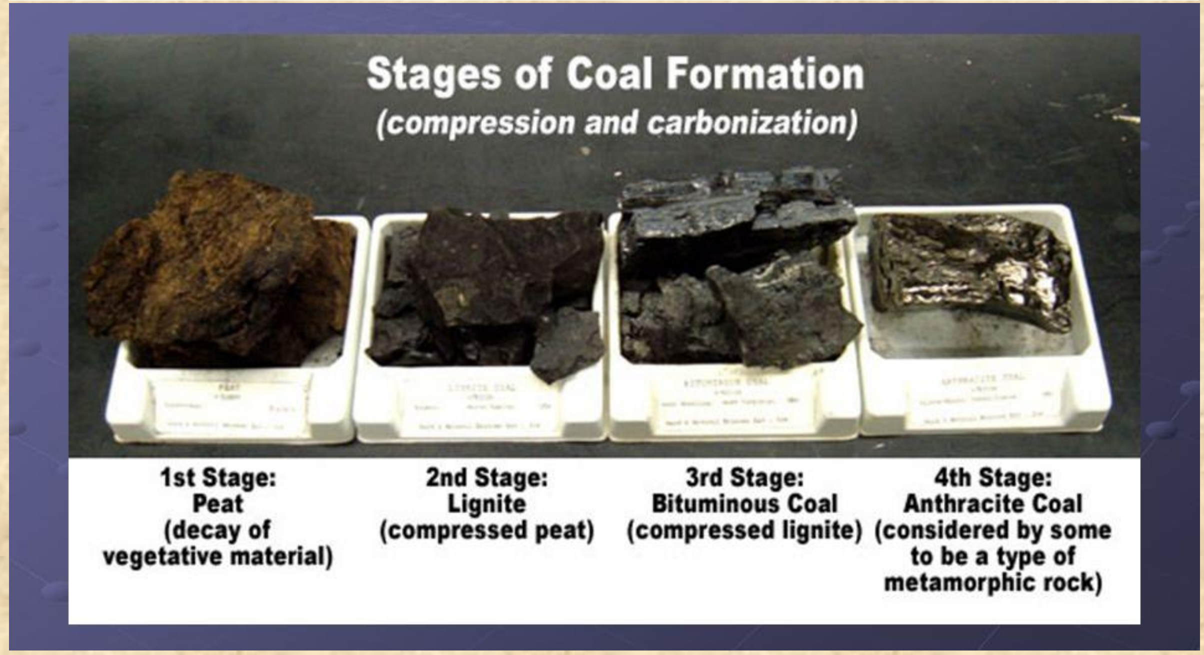




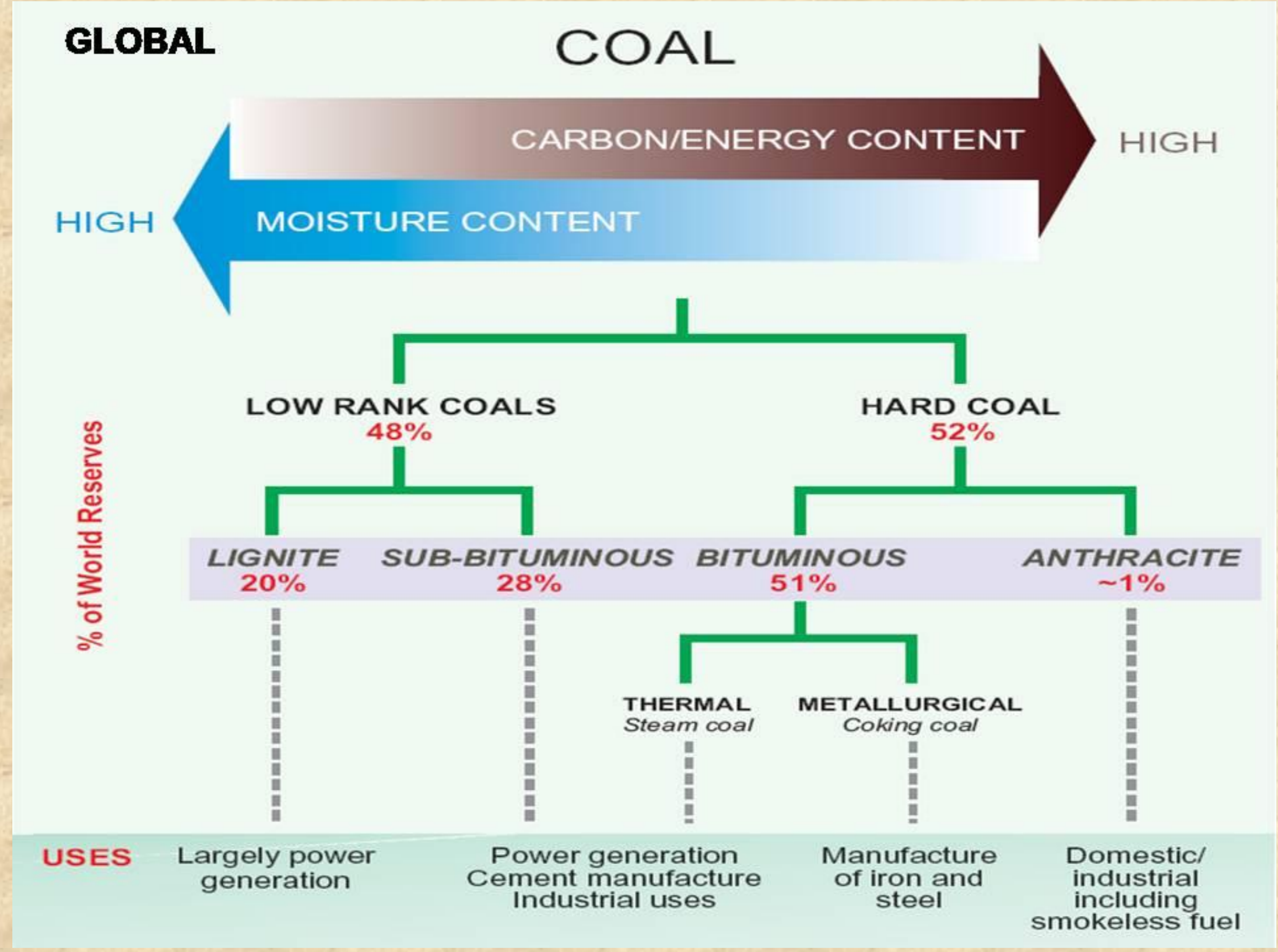
Formation of coal

- Time
- Temperature
- Pressure

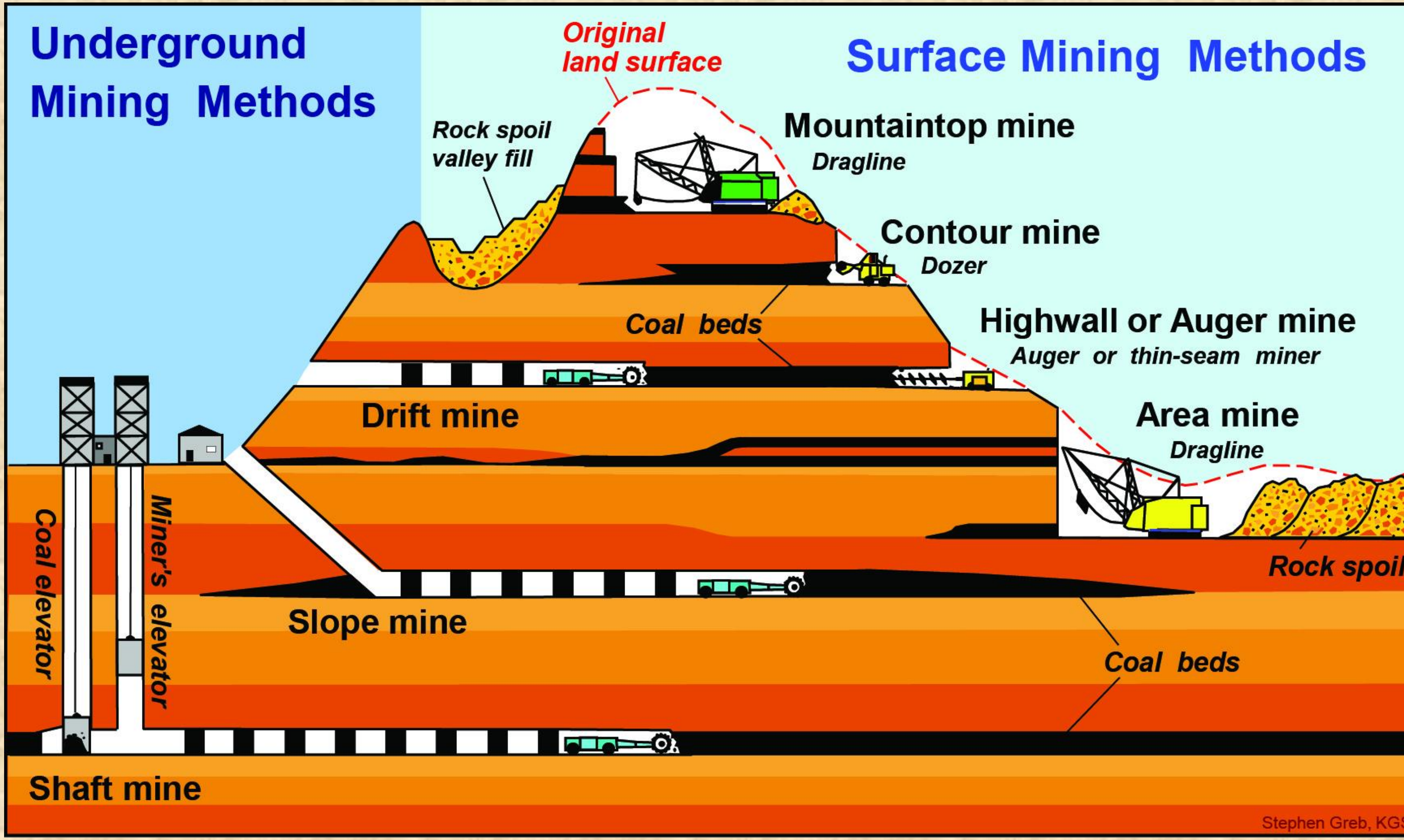




Higher rank coals have higher heating value – more carbon, less water



Various coal mining methods and environmental impacts




Coal

- Environmental impacts of coal mining:
  - Substantial effects on the environment
    - Topsoil loss (from erosion or removal during mining) prevents restoration of site
    - Landslides occur due to loss of soil-stabilizing vegetation

Coal

- Environmental impacts of coal mining:
  - Acid and toxic mineral drainage leaches from minerals exposed in mine waste
    - Acid mine drainage—sulfuric acid and dangerous dissolved materials, such as lead, arsenic, and cadmium, wash from coal and metal mines into nearby lakes and streams
  - Streams become polluted with silt runoff and acid mine drainage

Chemistry of AMD

General equations for this process are:

- $2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$
- $4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$
- $4Fe^{3+} + 12H_2O \rightarrow 4Fe(OH)_3 + 12H^+$
- $FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$

The net effect of these reactions is to release H^+, which lowers the pH, produces sulphate ions.

Effect scenarios in some places

- About half of the coal mine discharges in Pennsylvania have pH under 5.
- In US >12,000 miles of river and 180,000 acres of lakes/reservoirs are adversely affected.
- US companies now spend >$1million/day to treat CMD prior to discharging;
- In the coal belt around the south Wales valleys in the UK highly acidic nickel-rich discharges from coal stocking sites have proved to be particularly troublesome.

Acid Mine Drainage

Chemical	Physical	Biological	Ecological
• Increased acidity • Increase in soluble metal concentrations & particulate metals • Destruction of bicarbonate buffering system	• Sedimentation • Increase in stream velocity • Increased turbidity • Decrease in light penetration	• Affects reproductive patterns of organism • Acute and Chronic toxicity • Death of sensitive species • Migration of species	• Habitat modification • Bio-accumulation • Reduction in primary production • Increased instability of food chain

AMD Control Strategies

- Containment and isolation

- Soil covers- by imported materials e.g. clay, soil

  - low sulphide waste-rock if compactable

  - Geo-textile fabrics

- Water cover- creation of a permanent lake or swamp

  - use of an existing lake

  - flooding of underground tunnels

  - submarine disposal

-Blending- mixing of acid and non acid forming waste rock

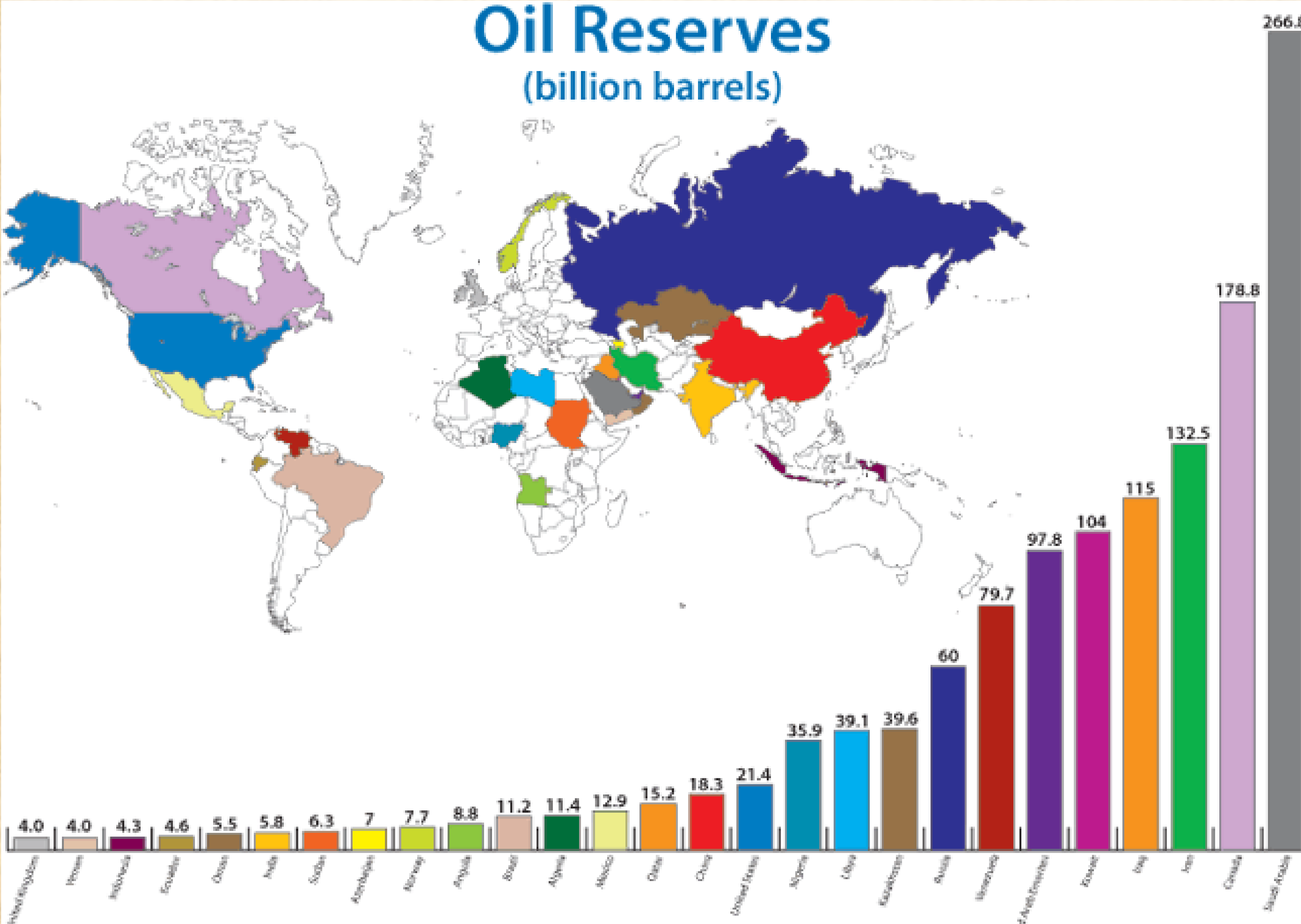
- Treatment- Using AMD remediation technologies

Coal

- Environmental impacts of coal mining
  - Mountaintop removal
    - One of most destructive mining methods
    - Has leveled 15–25% of mountains in southern West Virginia
      - Half the peaks in that area will be gone by 2020
    - Valleys and streams between mountains are obliterated; filled in with tailings and debris
    - Also in Kentucky, Pennsylvania, Tennessee, Virginia
    - http://earthobservatory.nasa.gov/Features/WorldOfChange/hobet.php
  - Surface Mining Control and Reclamation Act
    - 1977—controlled abandoned surface mines
    - Set standards for mines to follow during operation and reclamation

Oil Reserves

(billion barrels)



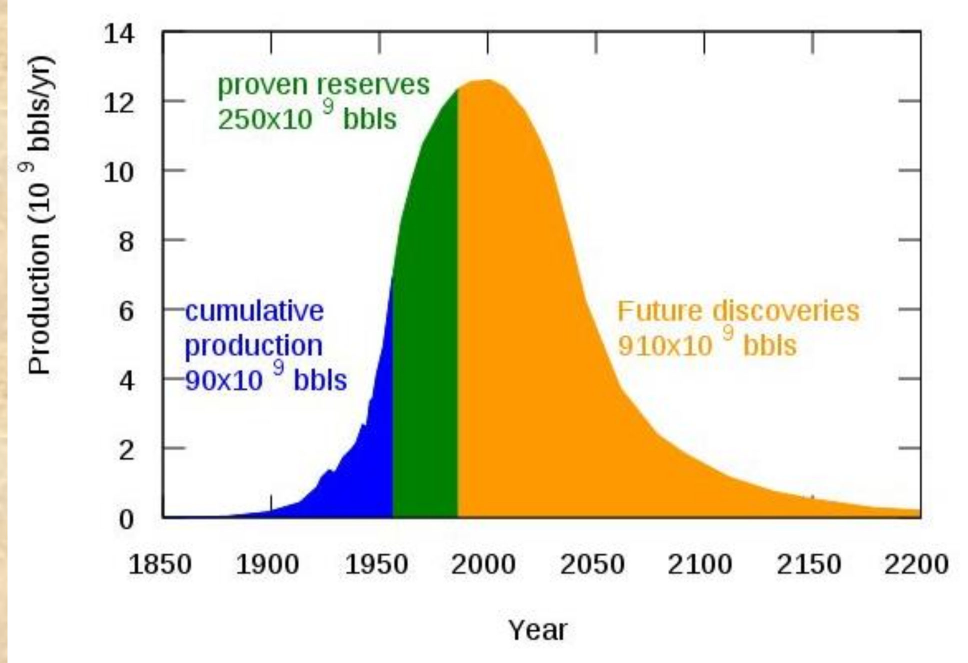
Data presented are for countries with 4 billion barrels of reserves or greater.
Source: Oil includes crude oil and condensate. Data for Canada include oil sands. *Oil and Gas Journal*, December 19, 2005. Data for the United States are from the Energy Information Agency, November 2005.

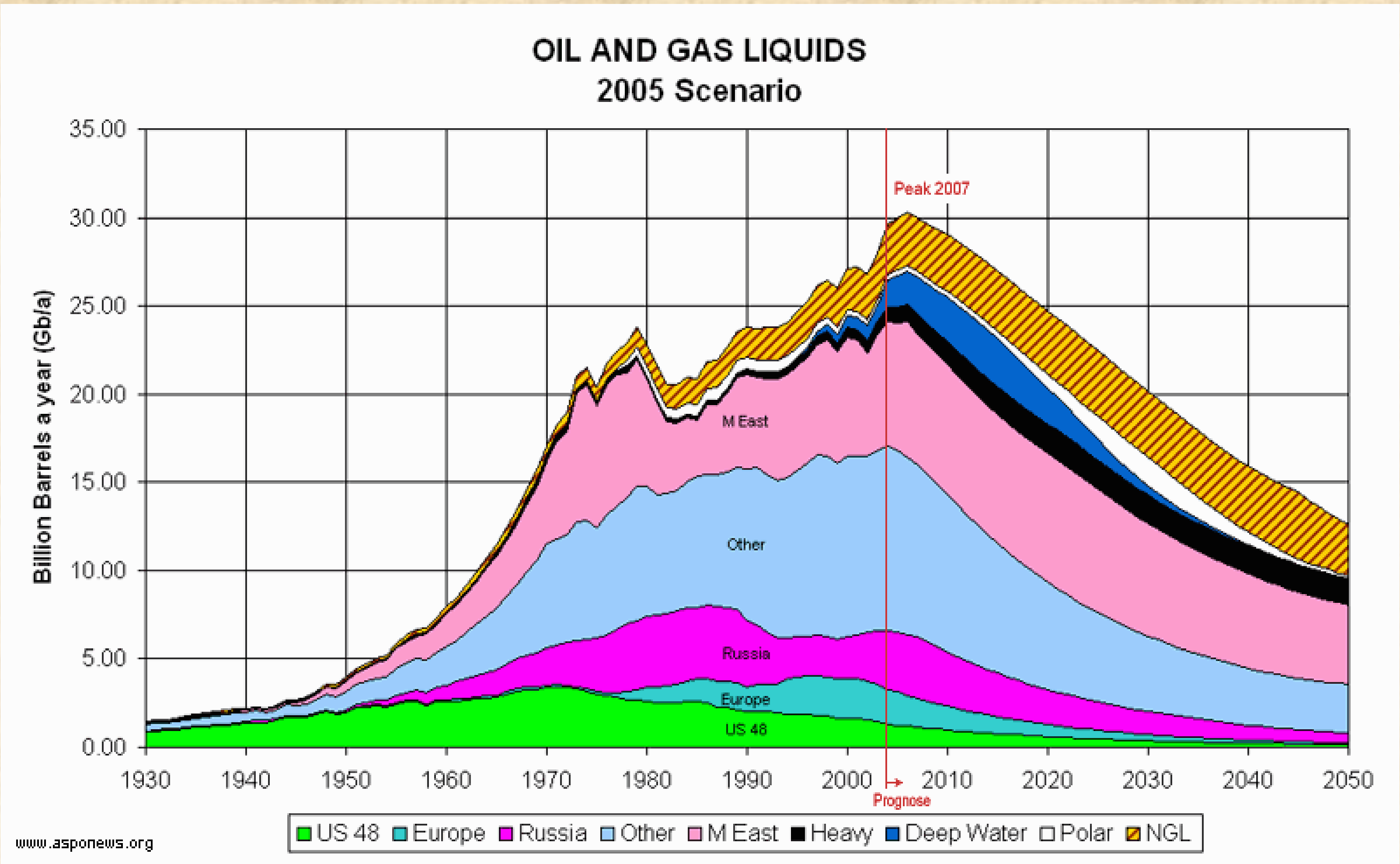
Hubbert curve

The prototypical Hubbert curve is a probability density function of a logistic distribution curve. It is not a gaussian function (which is used to plot normal distributions), but the two have a similar appearance. The density of a Hubbert curve approaches zero more slowly than a gaussian function.

The graph of a Hubbert curve consists of three key elements:
1. a gradual rise from zero resource production that then increases quickly
2. a "Hubbert peak", representing the maximum production level
3. a drop from the peak that then follows a steep production decline.

The actual shape of a graph of real world production trends is determined by various factors, such as development of enhanced production techniques, availability of competing resources, and government regulations on production or consumption. Because of such factors, real world Hubbert curves are often not symmetrical.

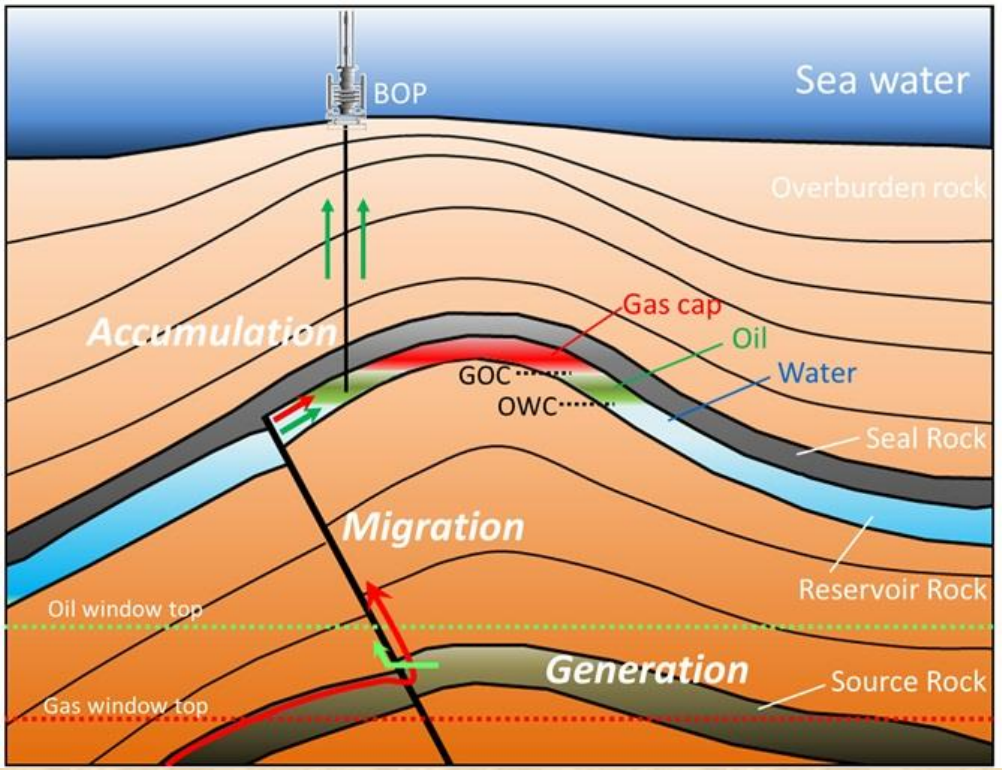


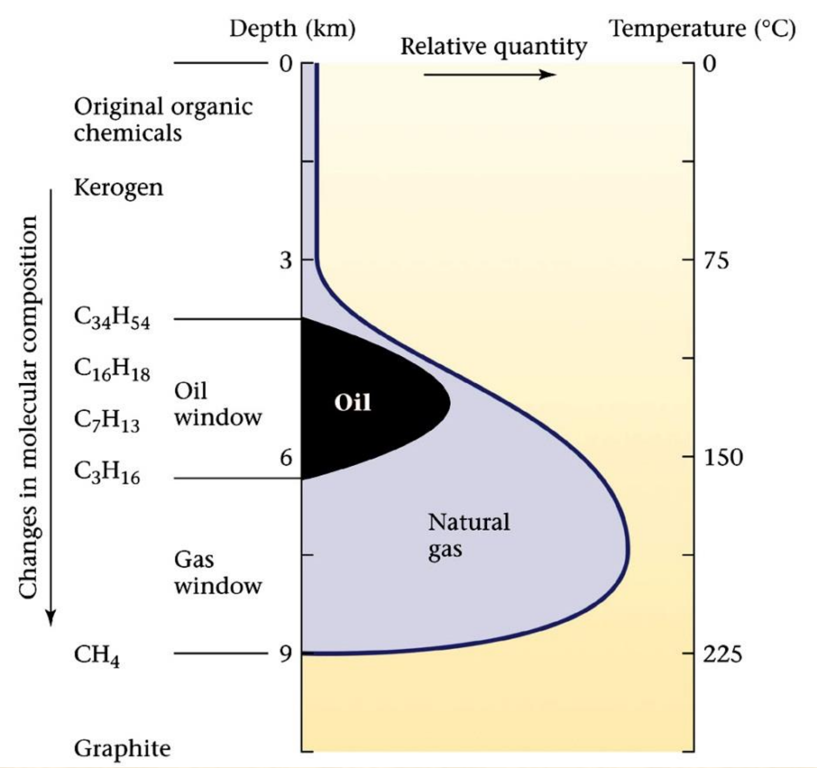


OIL AND GAS LIQUIDS
2005 Scenario
Billion Barrels a year (Gb/a)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Peak 2007
Prognose
M East
Other
Russia
Europe
US 48
US 48 Europe Russia Other M East Heavy Deep Water Polar NGL
www.asponews.org

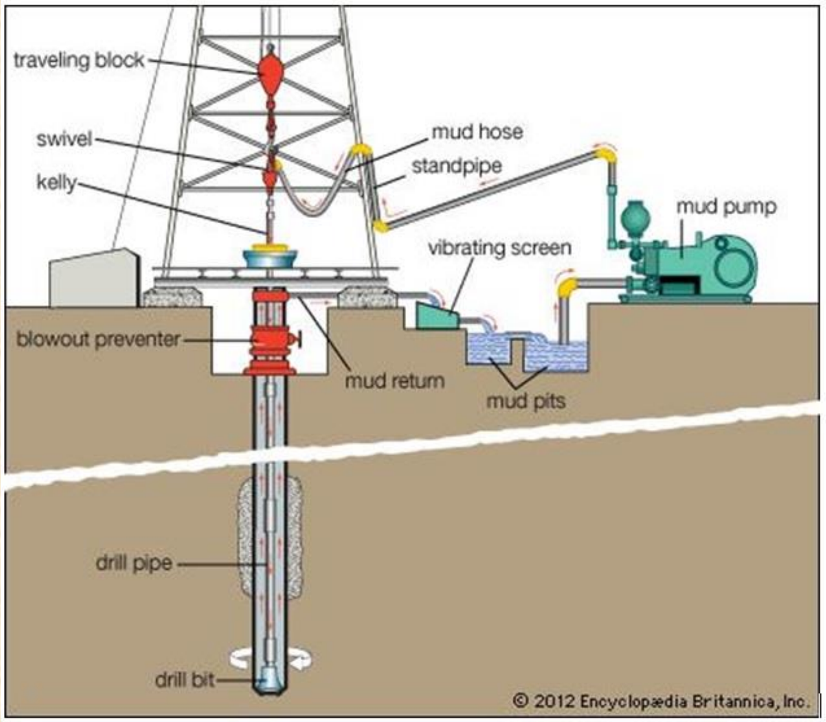
Formation of petroleum

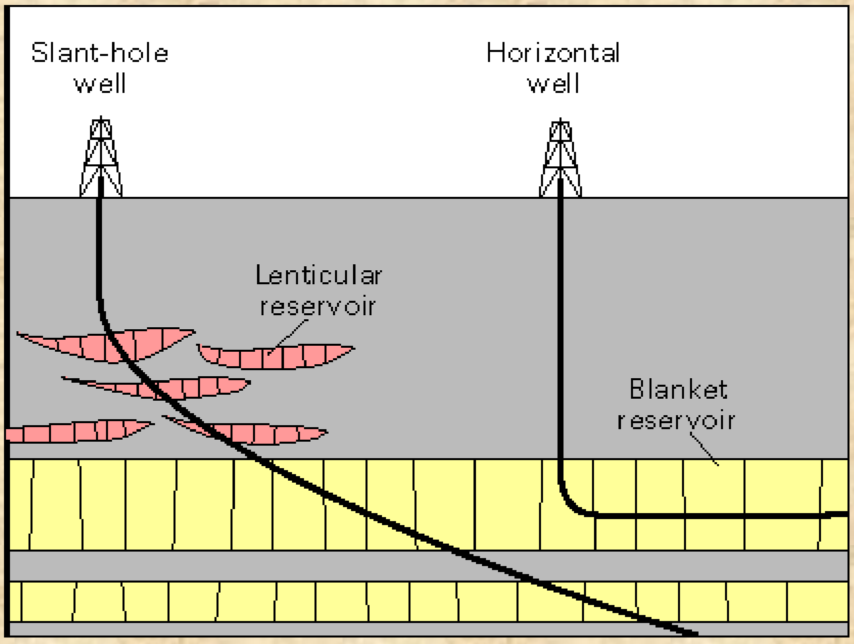
- Source rock
- Reservoir rock
- Trap



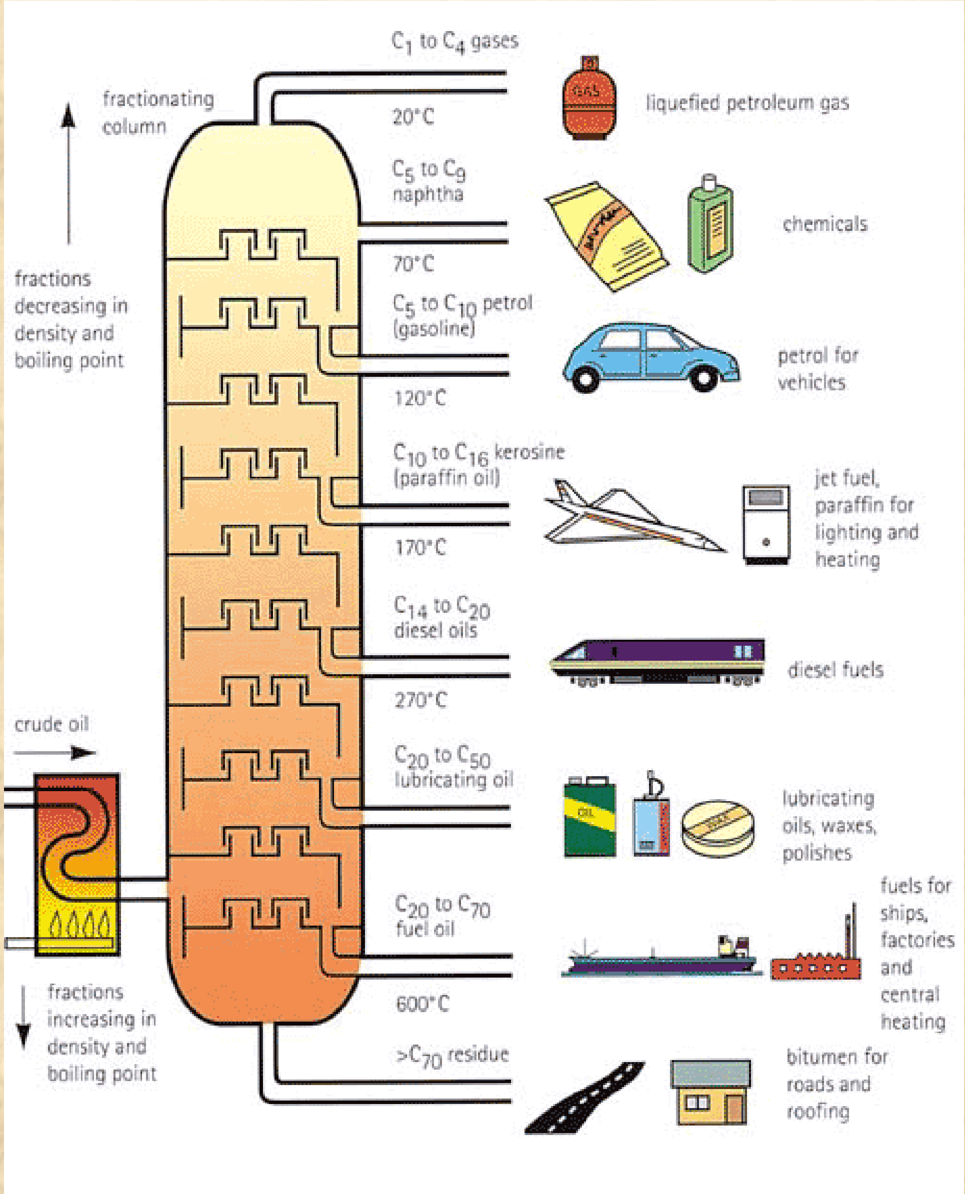


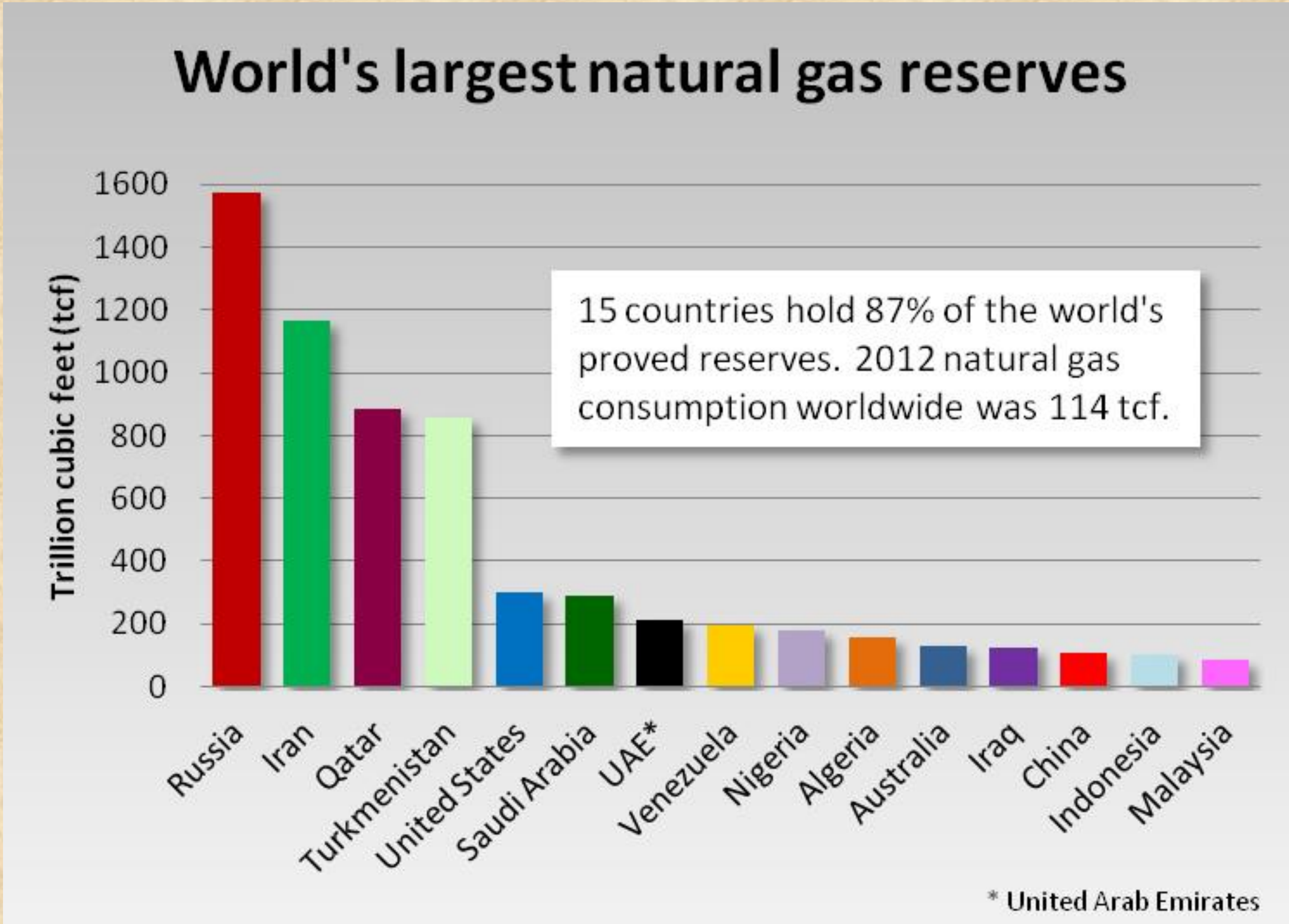
Drilling oil wells





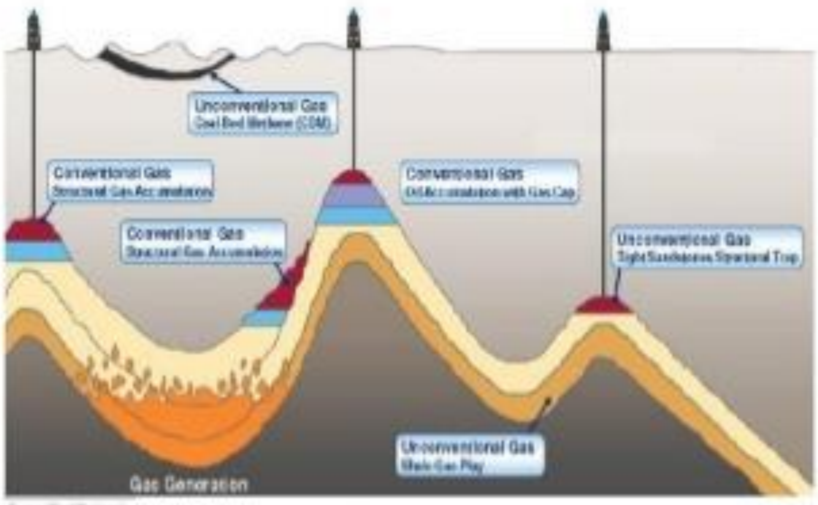
Oil refining




World's largest natural gas reserves
Trillion cubic feet (tcf)
1600
1400
1200
1000
800
600
400
200
0
15 countries hold 87% of the world's proved reserves. 2012 natural gas consumption worldwide was 114 tcf.
Russia
Iran
Qatar
Turkmenistan
United States
Saudi Arabia
UAE*
Venezuela
Nigeria
Algeria
Australia
Iraq
China
Indonesia
Malaysia
* United Arab Emirates

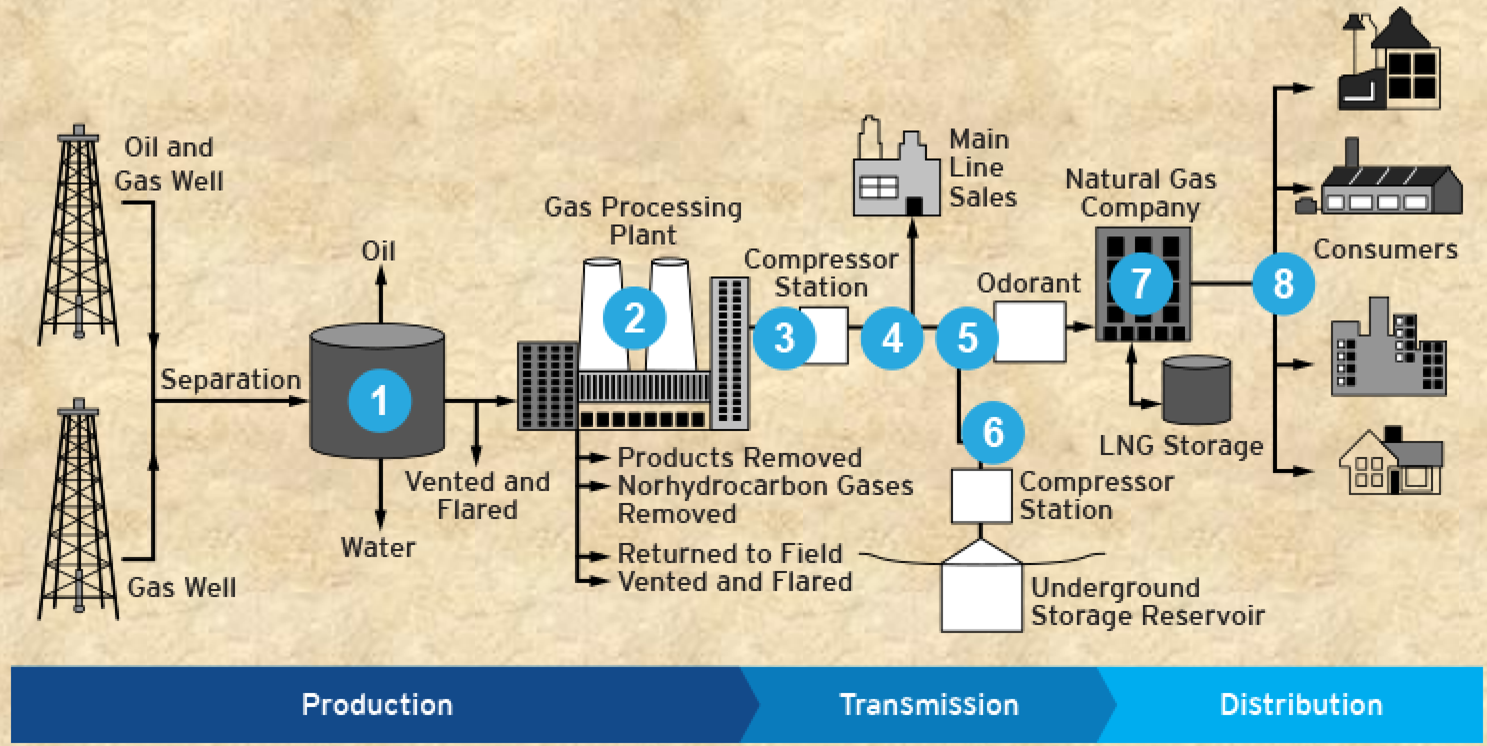
3) NATURAL GAS

- Natural Gas:
  - is a mixture of 50-90% methane (CH_4) by volume; contains smaller amounts of ethane, propane, butane and toxic hydrogen sulfide.
  - **Either Conventional natural gas or Unconventional deposits**.
- **Gas Hydrates:** an ice-like material that occurs in underground deposits (globally).
- **Liquefied Petroleum Gas (LPG):** propane and butane are liquefied and removed from natural gas fields. Stored in pressurized tanks.

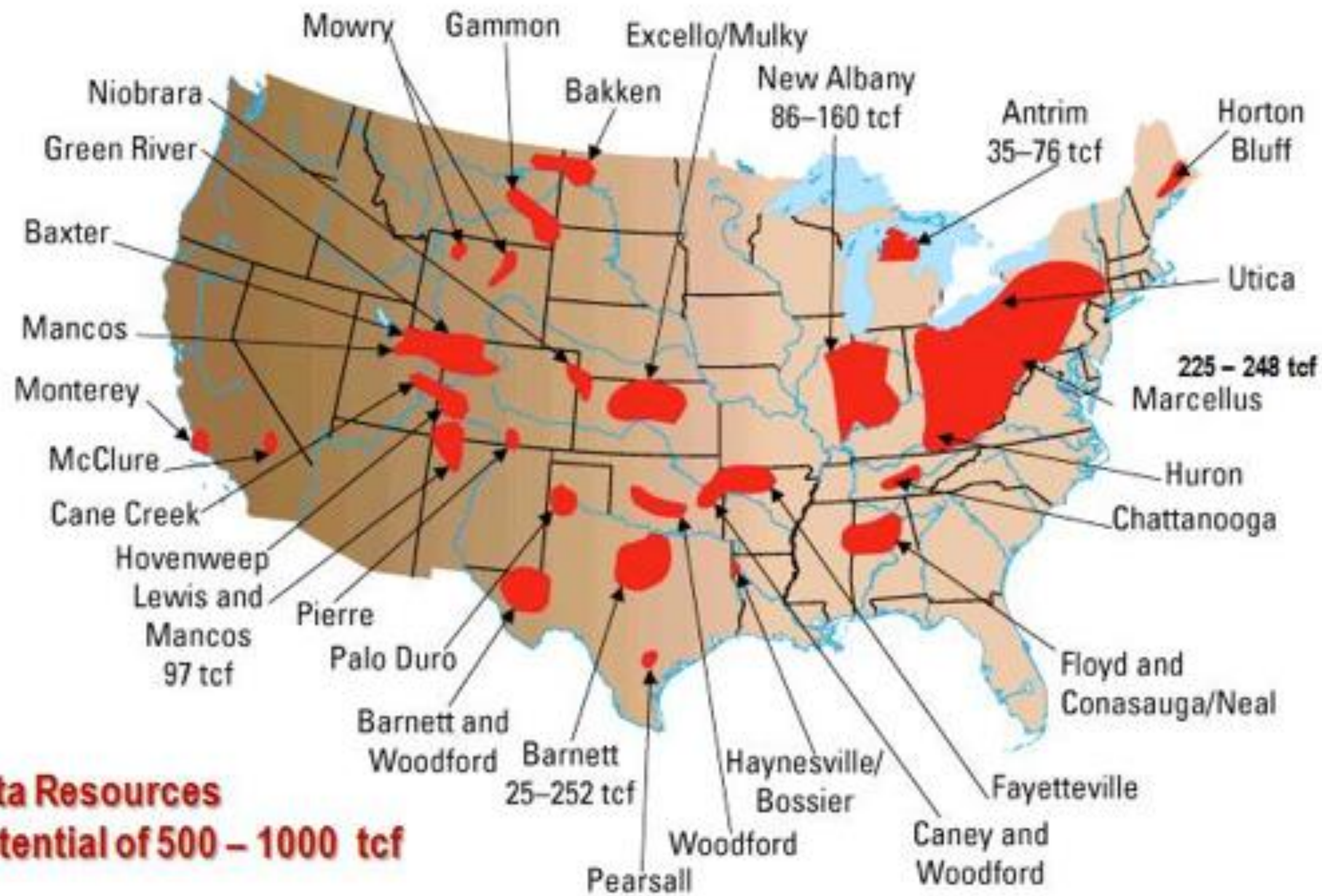


Types of Natural Gas Plays

Conventional gas	Unconventional gas
❑ Accumulations in medium to highly porous reservoirs with sufficient permeability to allow gas to flow to producing well. ❑ lies above most reservoirs of crude oil ❑ Pressure regime tends to moves gas toward producing well (i.e., natural flow).	❑ Deposits of natural gas found in relatively impermeable rock formations-Tight sand and coal beds. ❑ Include coal beds, shale rock, deep deposits of tight sands and deep zones that contain natural gas dissolved in hot water. ❑ To get resources out of the ground, artificial pathways (fractures) have to be created. ❑ Key technologies are horizontal drilling and hydraulic fracturing techniques. ❑ Need much higher number of extracting well


Oil and Gas Well
Gas Well
Separation
1
Oil
Water
Vented and Flared
Gas Processing Plant
2
Products Removed
Norhydrocarbon Gases Removed
Returned to Field
Vented and Flared
Compressor Station
3
Main Line Sales
4
5
Odorant
6
Compressor Station
Underground Storage Reservoir
Natural Gas Company
7
LNG Storage
8
Consumers
Production
Transmission
Distribution

Shale Gas Basins In The United States



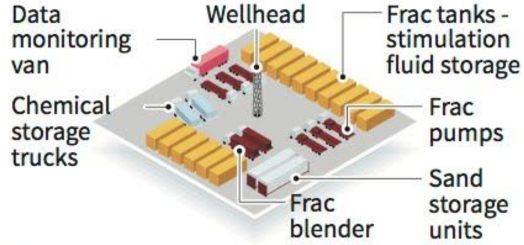
Tota Resources
Potential of 500 – 1000 tcf

Hydraulic fracturing - how it works

THE PROCESS

Hydraulic fracturing, commonly known as fracking, is the creation of fractures in rock formations in the earth using pressurised fluid, generally for the purpose of extracting natural gas

Common Fracturing Equipment

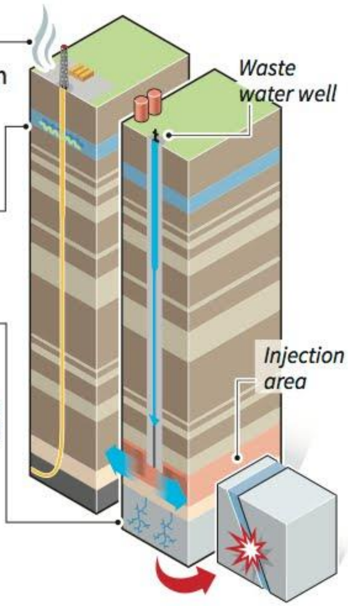


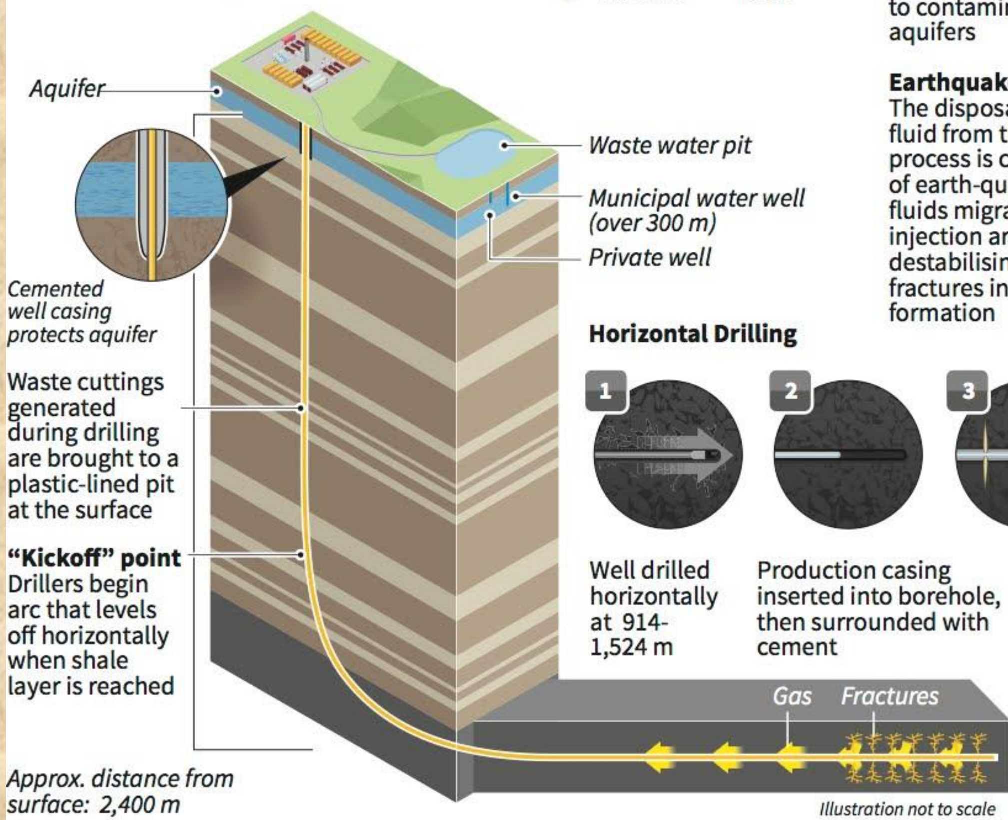
RISKS

Air emissions
Methane gas associated with natural gas extraction can leak into air

Drinking water
Chemicals used in fracking process have the potential to contaminate aquifers

Earthquakes
The disposal of waste fluid from the fracking process is cited as a cause of earth-quakes. Disposed fluids migrate below the injection area, destabilising the natural fractures in the rock formation





Horizontal Drilling

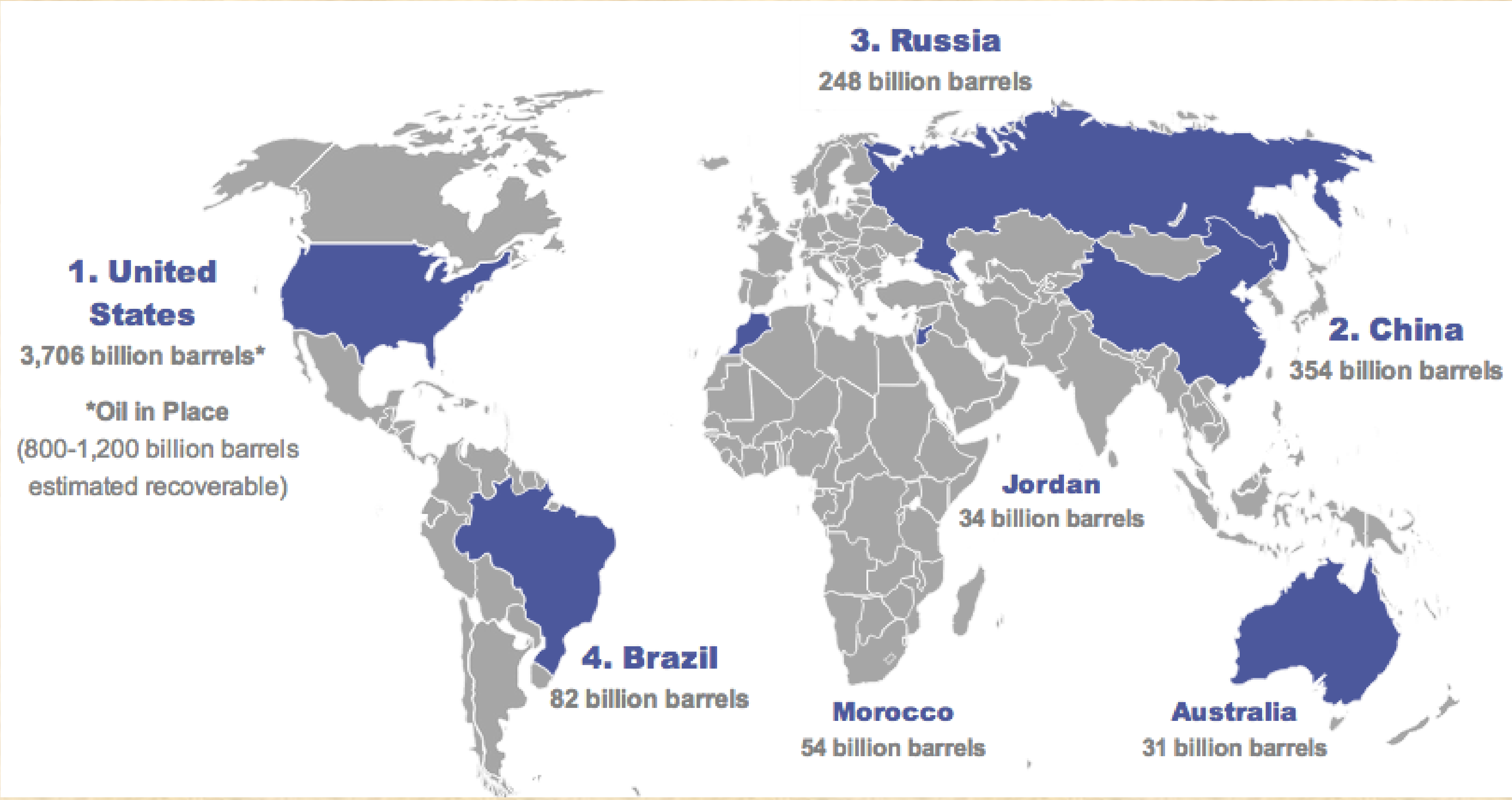
1. Well drilled horizontally at 914-1,524 m
2. Production casing inserted into borehole, then surrounded with cement
3. Charges then detonated inside a perforating gun, blasting small holes into the shale
4. Pressurised mixture of water, sand and chemi-cals then pumped into the well at 15,900 litres a minute
5. The fluid generates numerous small fissures in the shale, freeing trapped gas that flows to the surface

Sources: National Geographic, Chesapeake Energy, EIA., USGS

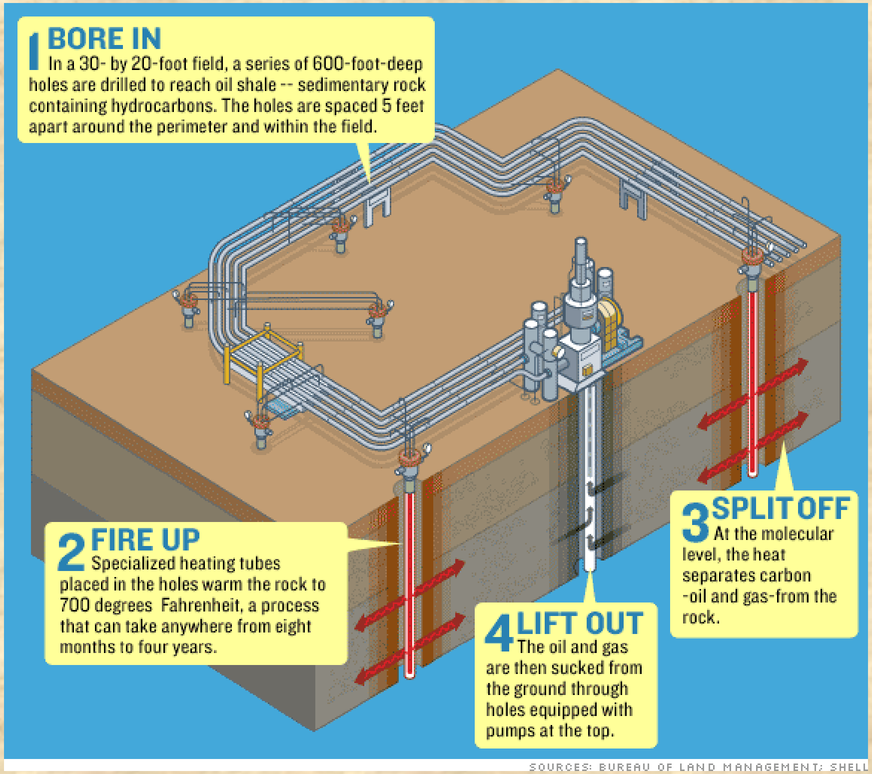
Staff, 24/12/2012

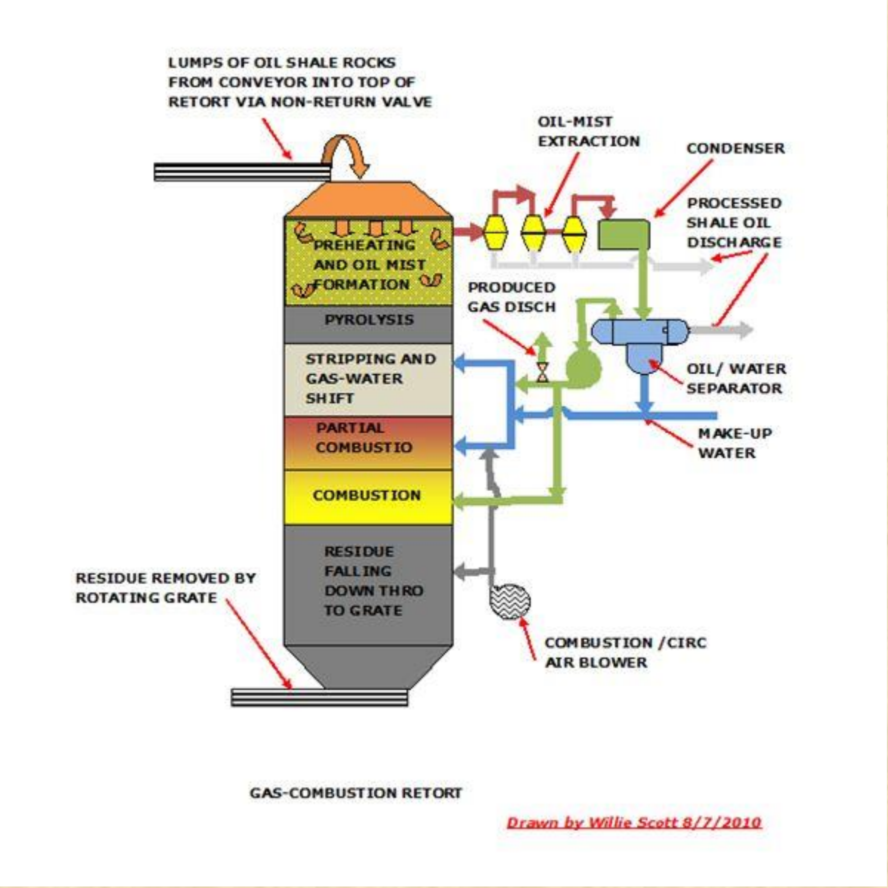
REUTERS

Oil shale reserves



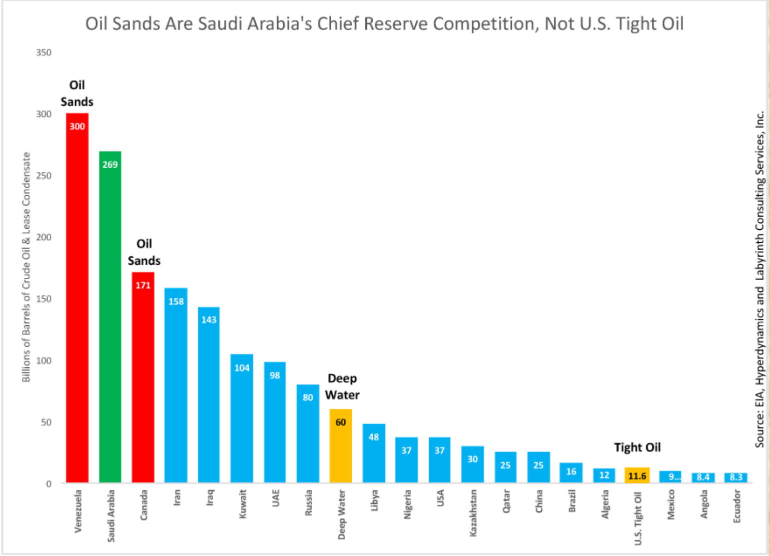
Oil shale – extraction (mining or wells) and processing

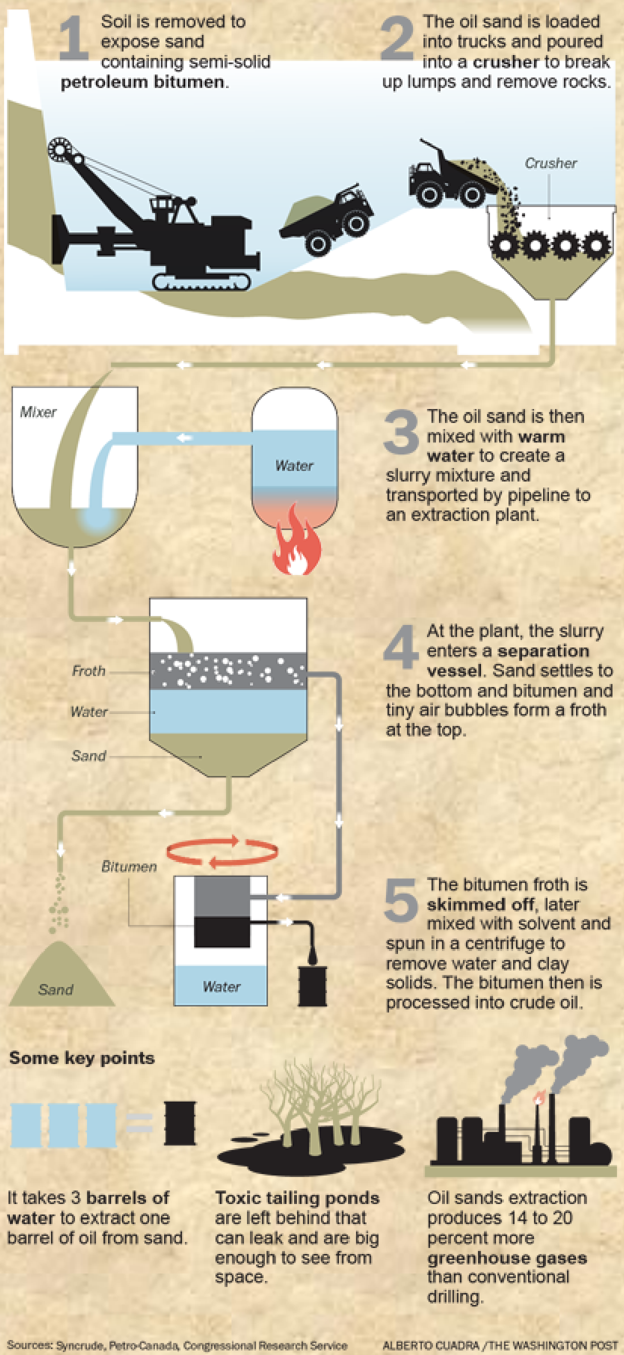




Tar Sands

- Contain Bitumen
  - Semi solid; doesn't "flow"
- Mined – strip mined
  - Steamed in place
- 5% sulfur content
- Most reserves in Canada & Venezuela
- Net energy yield – moderate
- Problems:
  - Acid rain, air pollution, global warming




1 Soil is removed to expose sand containing semi-solid **petroleum bitumen**.
2 The oil sand is loaded into trucks and poured into a **crusher** to break up lumps and remove rocks.
Crusher
Mixer
Water
3 The oil sand is then mixed with **warm water** to create a slurry mixture and transported by pipeline to an extraction plant.
Froth
Water
Sand
4 At the plant, the slurry enters a **separation vessel**. Sand settles to the bottom and bitumen and tiny air bubbles form a froth at the top.
Bitumen
Sand
Water
5 The bitumen froth is **skimmed off**, later mixed with solvent and spun in a centrifuge to remove water and clay solids. The bitumen then is processed into crude oil.
Some key points
It takes 3 **barrels of water** to extract one barrel of oil from sand.
Toxic tailing ponds are left behind that can leak and are big enough to see from space.
Oil sands extraction produces 14 to 20 percent more **greenhouse gases** than conventional drilling.
Sources: Syncrude, Petro-Canada, Congressional Research Service
ALBERTO CUADRA /THE WASHINGTON POST

Combustion Stoichiometry

- Coal: $CH + 1.25O_2 + 4.64N_2 \rightarrow CO_2 + 0.5H_2O + 4.64N_2$
- Oil: $CH_2 + 1.5O_2 + 5.565N_2 \rightarrow CO_2 + 1.5H_2O + 5.565N_2$
- Gas: $CH_4 + 2O_2 + 7.42N_2 \rightarrow CO_2 + 2H_2O + 7.42N_2$

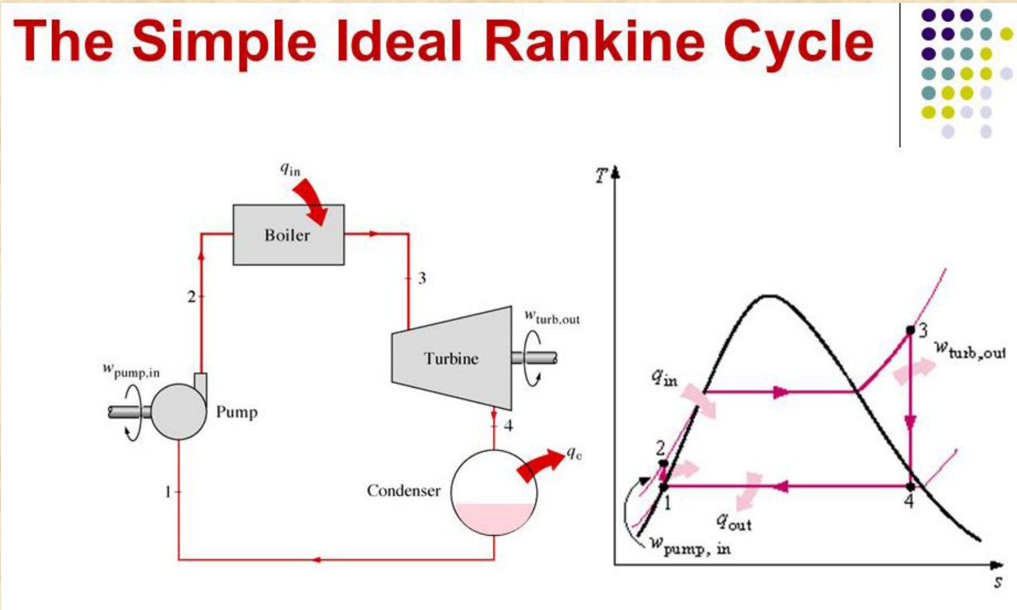
Combustion of typical coal in 20% excess air:

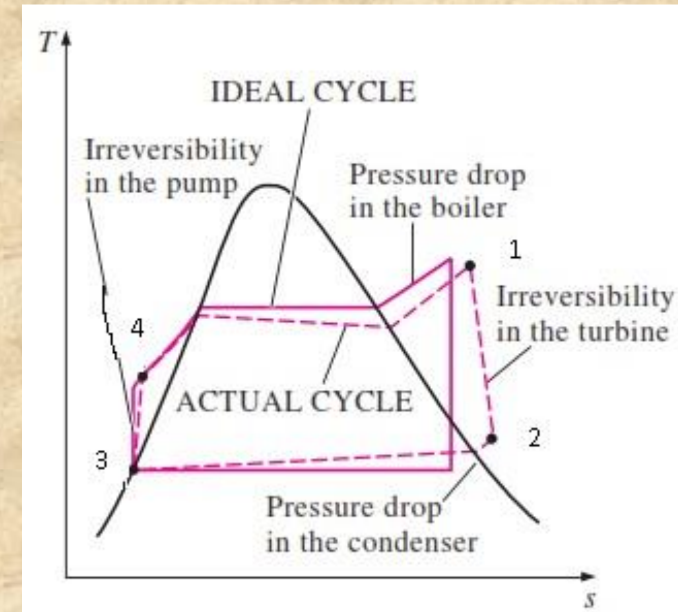
$$CHS_{0.02}N_{0.01} + 1.536O_2 + 5.698N_2 \rightarrow CO_2 + 0.5H_2O + 0.02SO_2 + 0.01NO_2 + 5.698N_2 + 0.307O_2$$

Total number of moles of flue gas from the above reaction = 7.535

Volume fraction (mole) of the individual flue gas	
N_2	75.6%
O_2	4.1%
CO_2	13.3%
SO_2	2654 ppmv
NO_2	1327 ppmv

Rankine cycle – external combustion system that generates steam to drive a turbine.



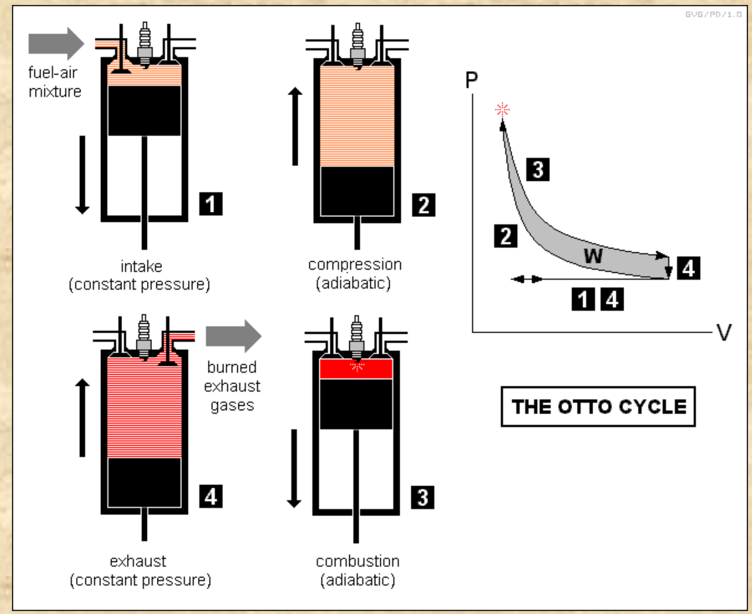


Steps in Rankine cycle

1. Ambient temperature water pumped to high pressure and injected into a boiler
2. Water heated to boiling point
3. Water completely turned into steam
4. Heated further to a higher temperature
5. Steam flows through a turbine and generates mechanical power. There is a reduction in pressure
6. The low pressure steam leaving the turbine is cooled to an ambient temperature liquid.
7. Pumped back into boiler completing the cycle

$W_t = H_1 – H_2 = \Delta H = V\Delta P$

A high-pressure high-temperature steam cycle is one in which steam T and P exceed the critical point of water. One can also superheat the steam to increase the efficiency. The thermodynamic efficiency for the Rankine cycle is between 30 – 45%



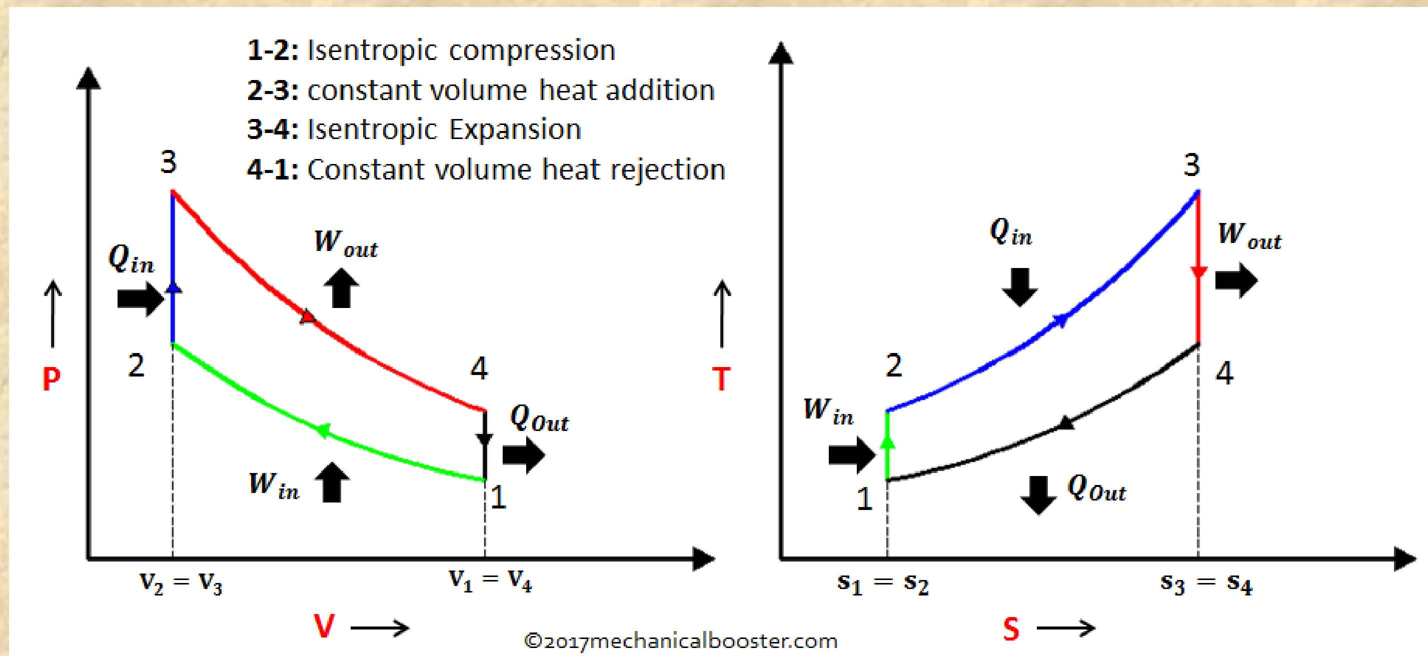
Otto Cycle – closed cycle versus the open Rankine cycle. Energy is generated internally through the combustion of a fuel. The process is considered to be adiabatic.

$$n_{th} = 1 - \frac{1}{(v_e/v_c)^{\frac{c_p}{c_v}-1}}$$

v_c = volume after compression stroke and v_e = volume after expansion.

Ideal efficiency ≈ 44%

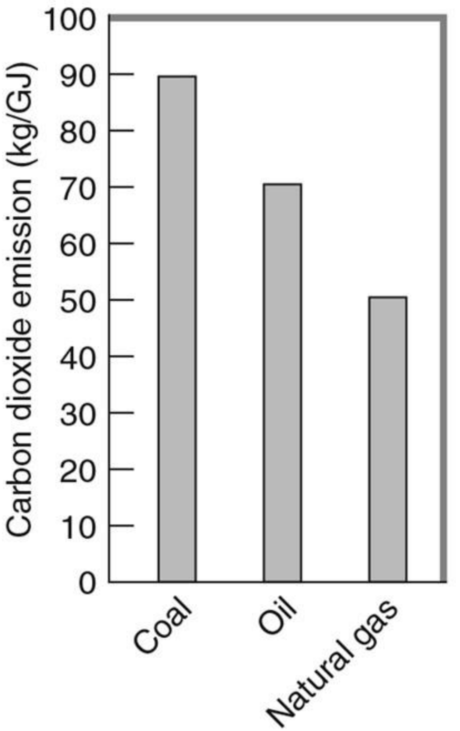
Real efficiency ≈28%



P-V and T-S Diagram of Otto Cycle

FIGURE 5.7

Carbon dioxide emission per gigajoule of energy released in the combustion of the three main types of fossil fuels. Natural gas produces just over half the CO_2 of coal, which makes it a more climate-friendly fuel.



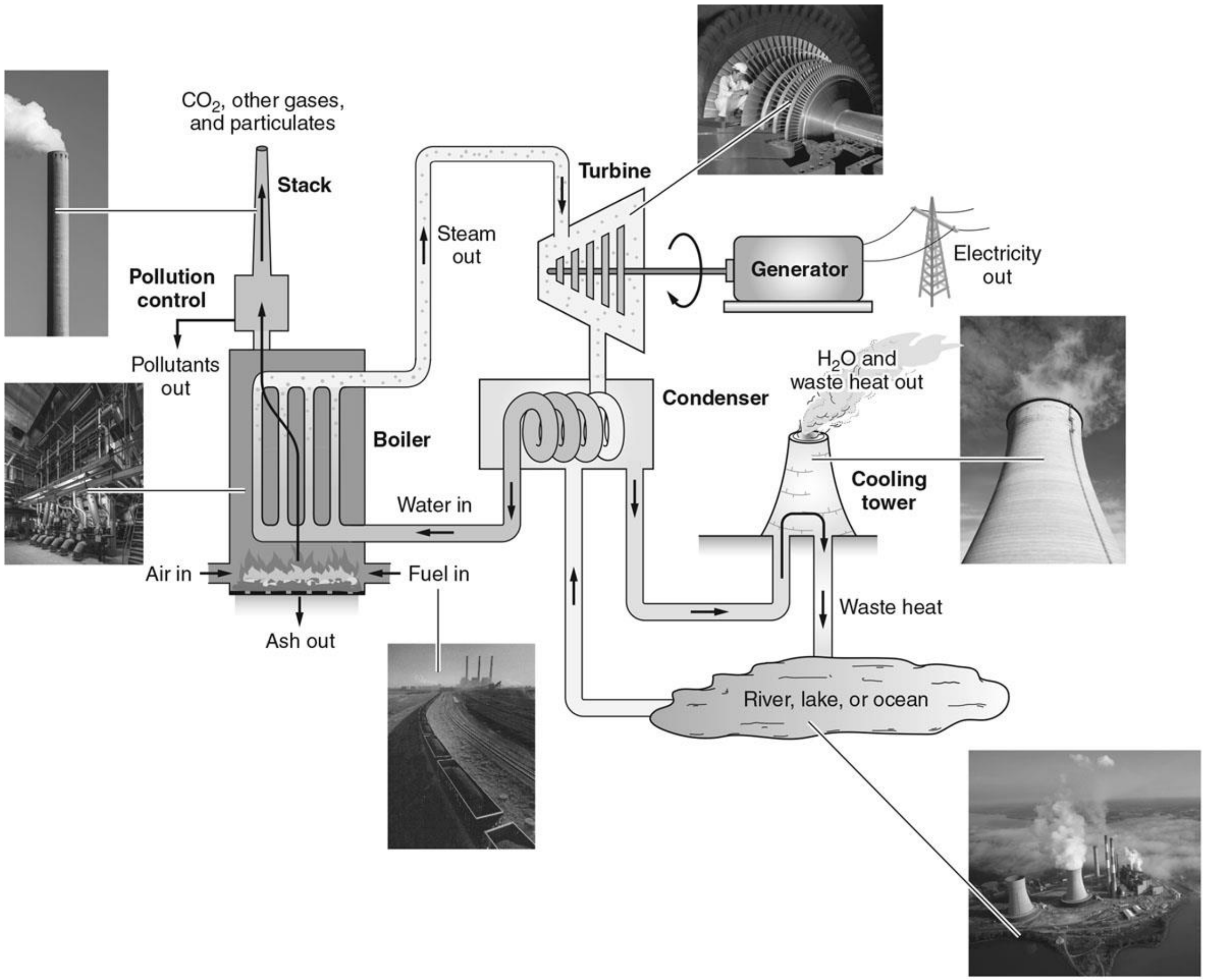


FIGURE 5.9

Diagram of a typical fossil-fueled power plant.

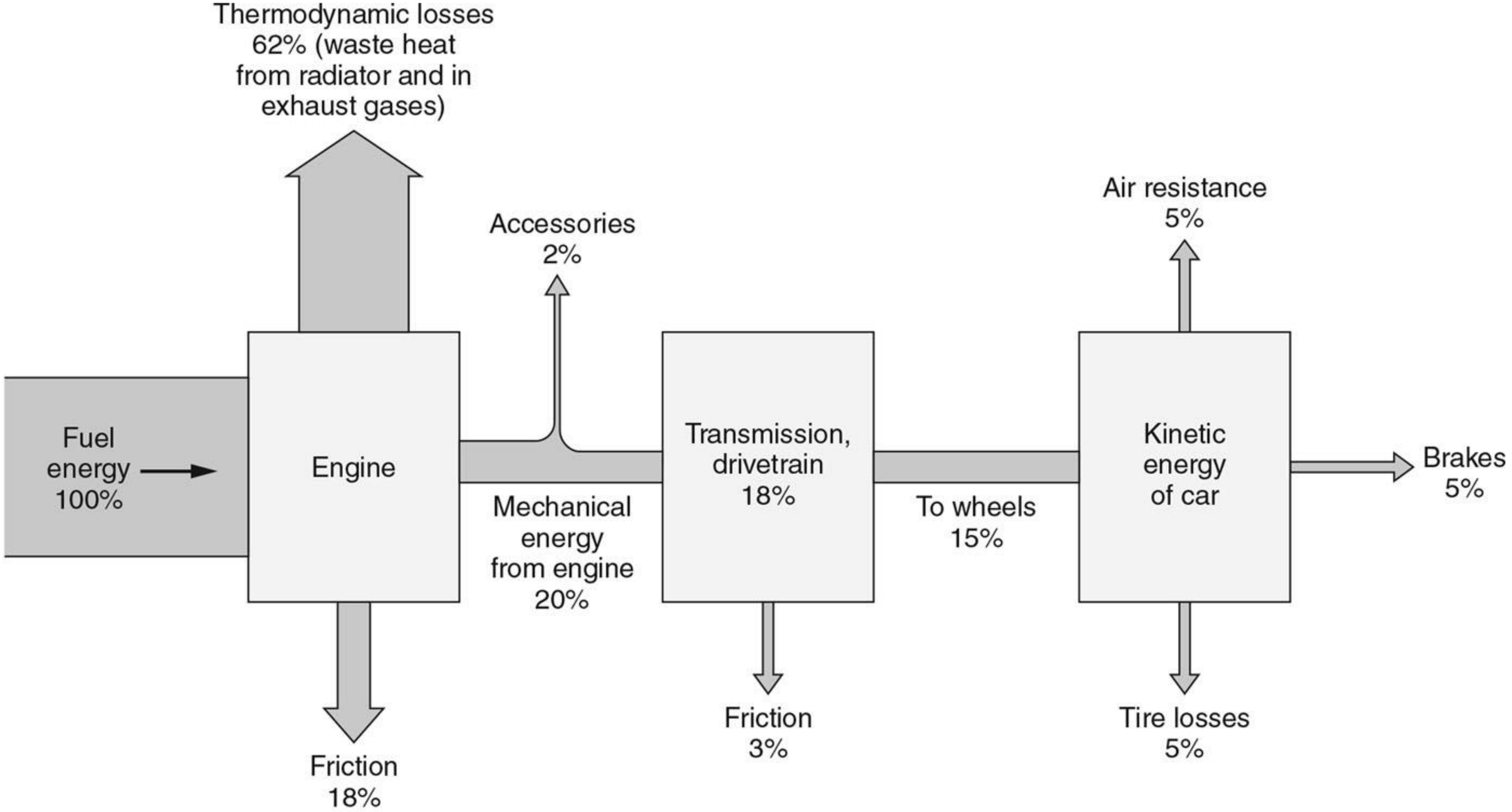


FIGURE 5.11

Energy flows in a typical gasoline-powered car. Thermodynamic losses and friction leave only about 15% of the fuel energy available at the wheels, all of which is dissipated by air resistance, tire friction, and braking. The power needed for accessories runs the air conditioning, lights, audio system, and vehicle electronics.

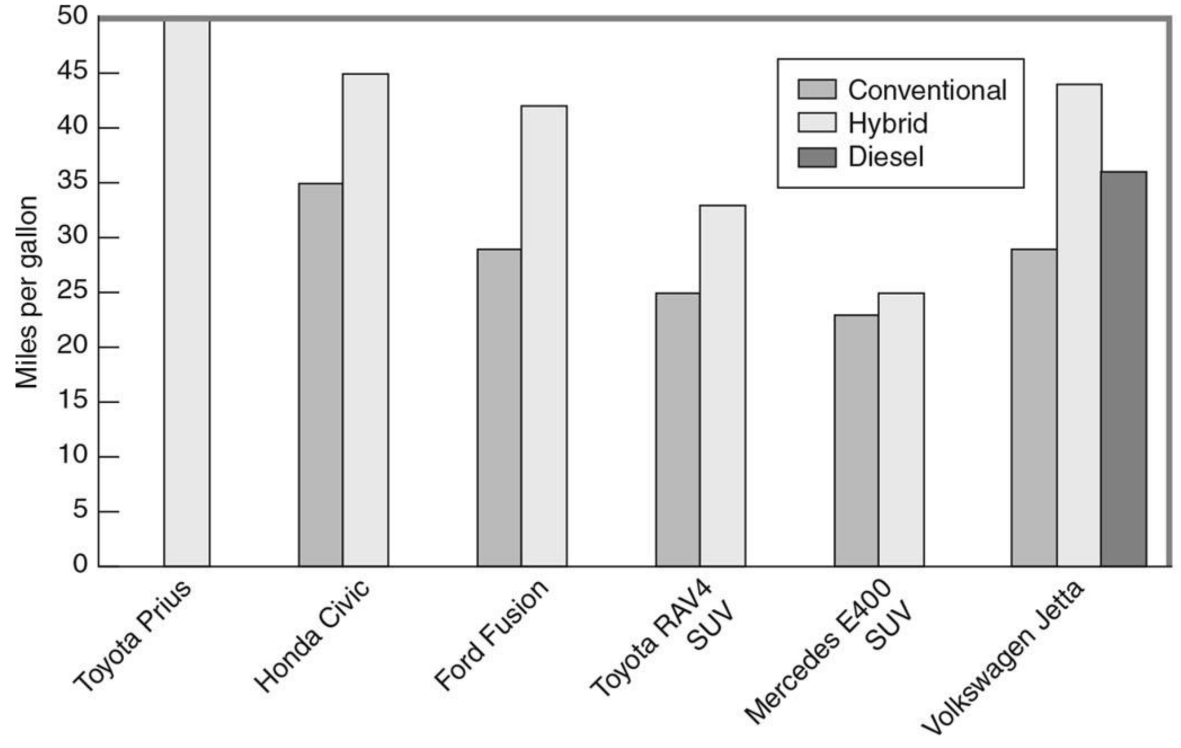


FIGURE 5.12

Fuel efficiencies of conventional, hybrid, and diesel vehicles for 2015 and 2016 model years.

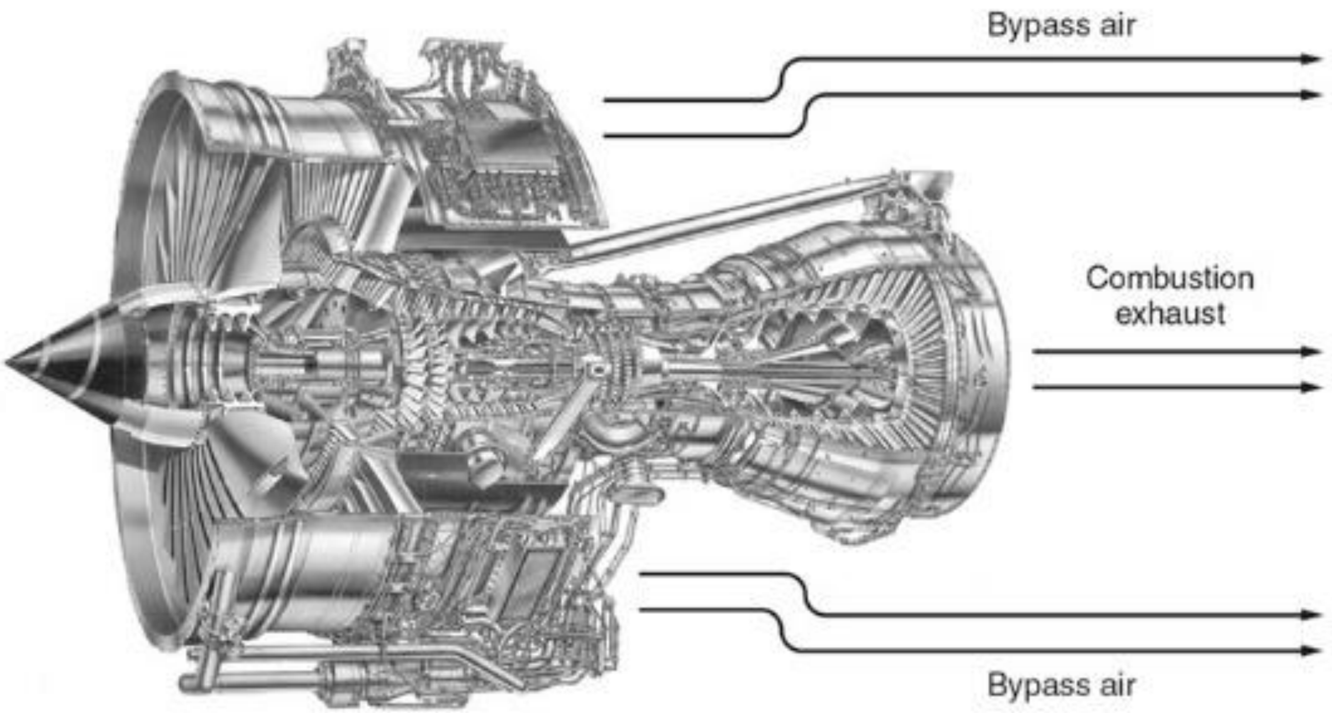


FIGURE 5.14

A jet aircraft engine is an example of a continuous combustion gas turbine. At left are a fan and compressor that pressurize incoming air. Some compressed air enters the combustion chamber, providing oxygen for fuel combustion. The resulting hot gases turn turbines that drive the compressors. As they exit at the right, the exhaust gases also provide some of the jet's thrust. But in a modern jet engine, most of the thrust comes from so-called bypass air that's diverted around the combustion chamber—a design feature that increases fuel efficiency.

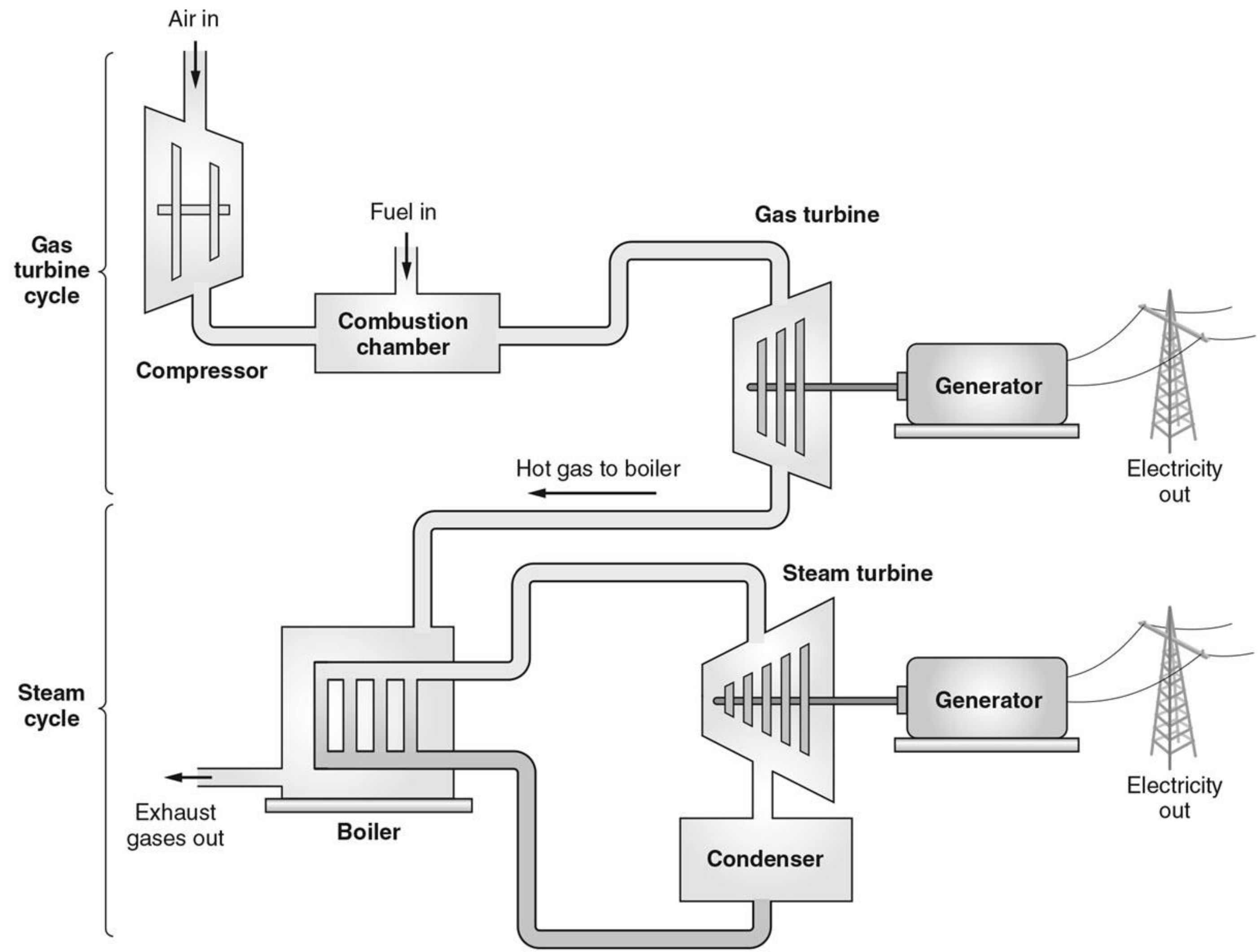


FIGURE 5.15

Diagram of a combined-cycle power plant. The steam cycle is similar to the one illustrated in Figure 5.9, although details of the cooling and exhaust systems aren't shown. Hot gas from the gas turbine replaces burning fuel in the steam boiler.

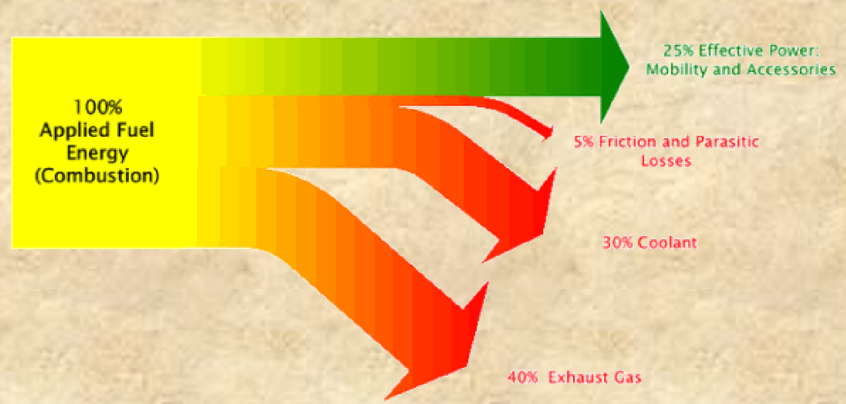
$$\dot{m}_f = \frac{P}{\eta_f (FHV)}$$

$\dot{m}_f$ = fuel mass consumption rate of an engine.

P = power output

η_f = fuel efficiency = ratio of the work produced to the heating value of the fuel consumed.

Typical Energy Split in Gasoline Internal Combustion Engines



Fuel (Thermal) Efficiencies of Current Power Technologies

Type	Efficiency (%)
Steam electric power plant	
Steam at 62 bar, 480°C	30
Steam at 310 bar, 560°C	42
Nuclear Power plant	
Steam at 70 bar, 286°C	33
Automotive gasoline engine	25
Automotive diesel engine	35
Gas turbine electric power plant	30
Combined cycle electric power plant	43
Fuel cell electric power	45