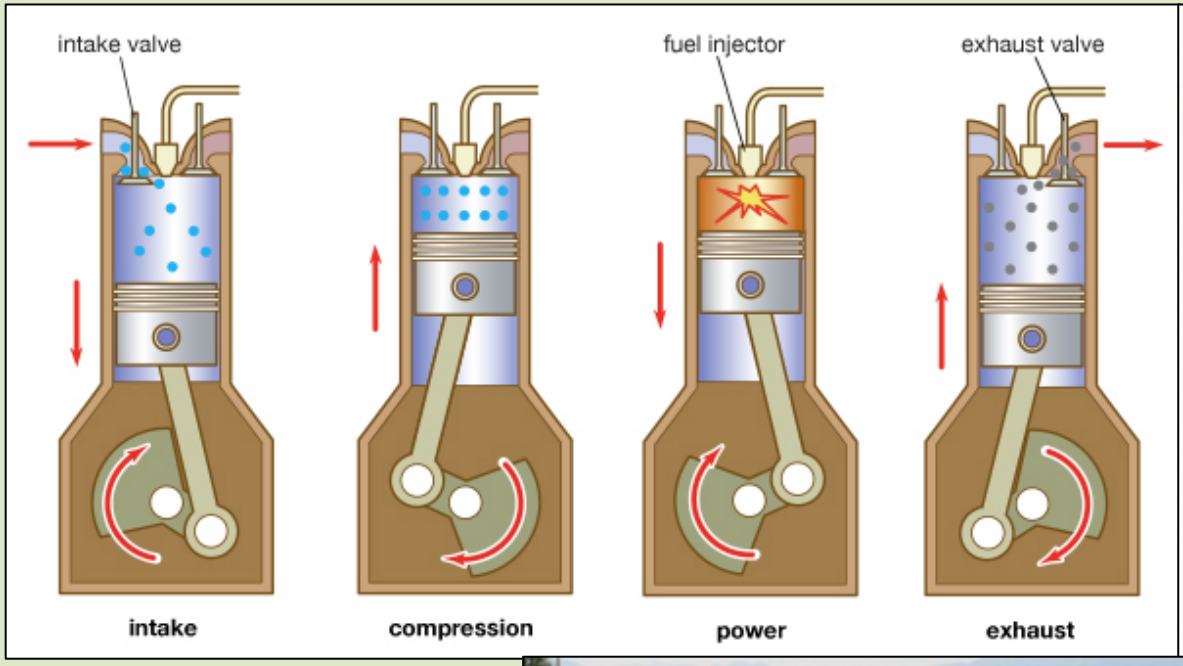
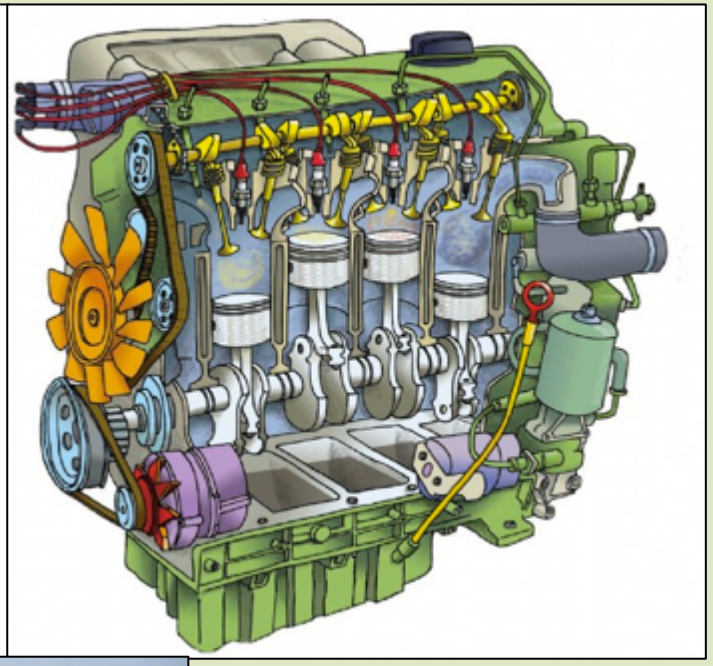
CHAPTER 15

Energy Introduction & Nonrenewable Energy: Fossil Fuels

Fossil Fuels Power Our Society

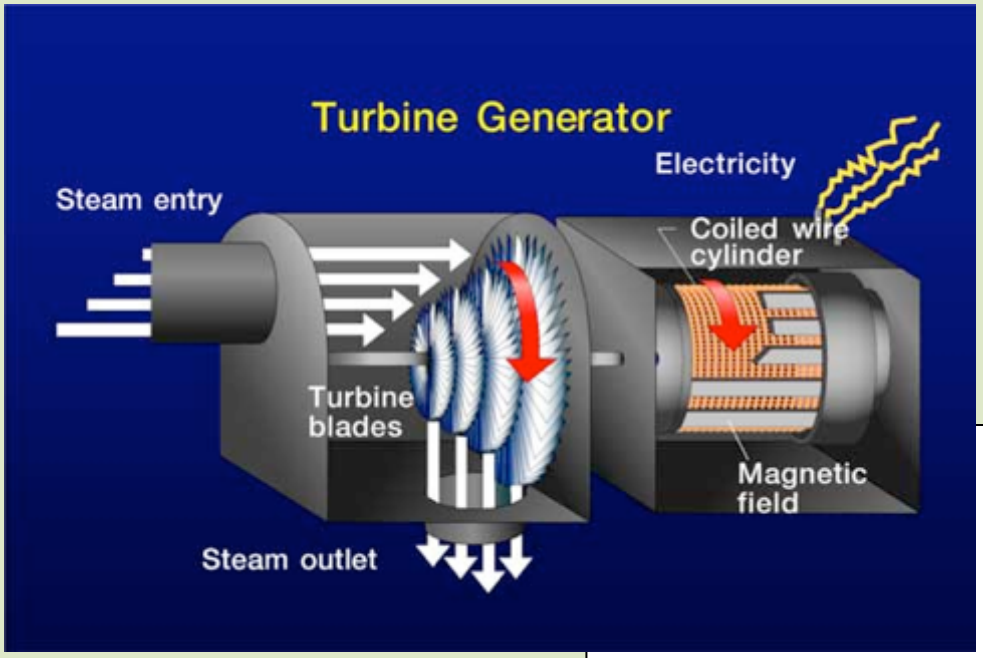
Automobiles are powered by the internal combustion engine, which is fueled by oil: gasoline or diesel.

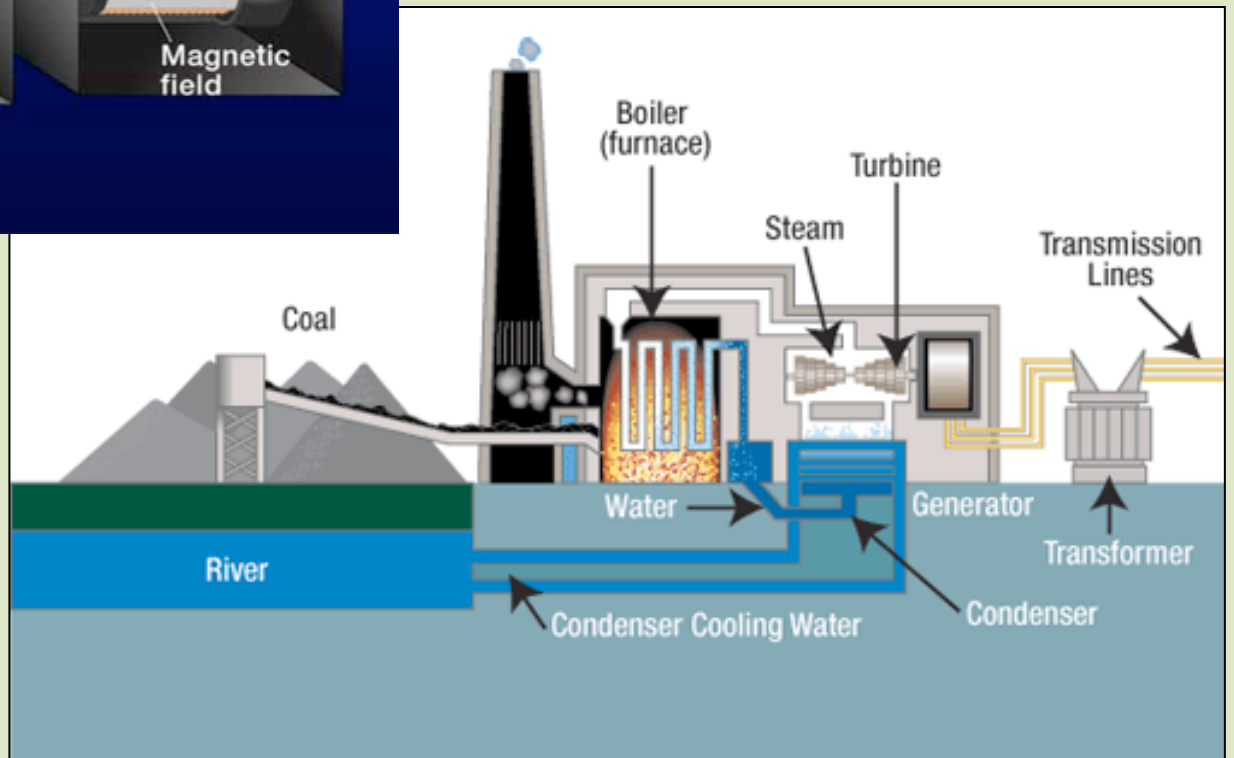




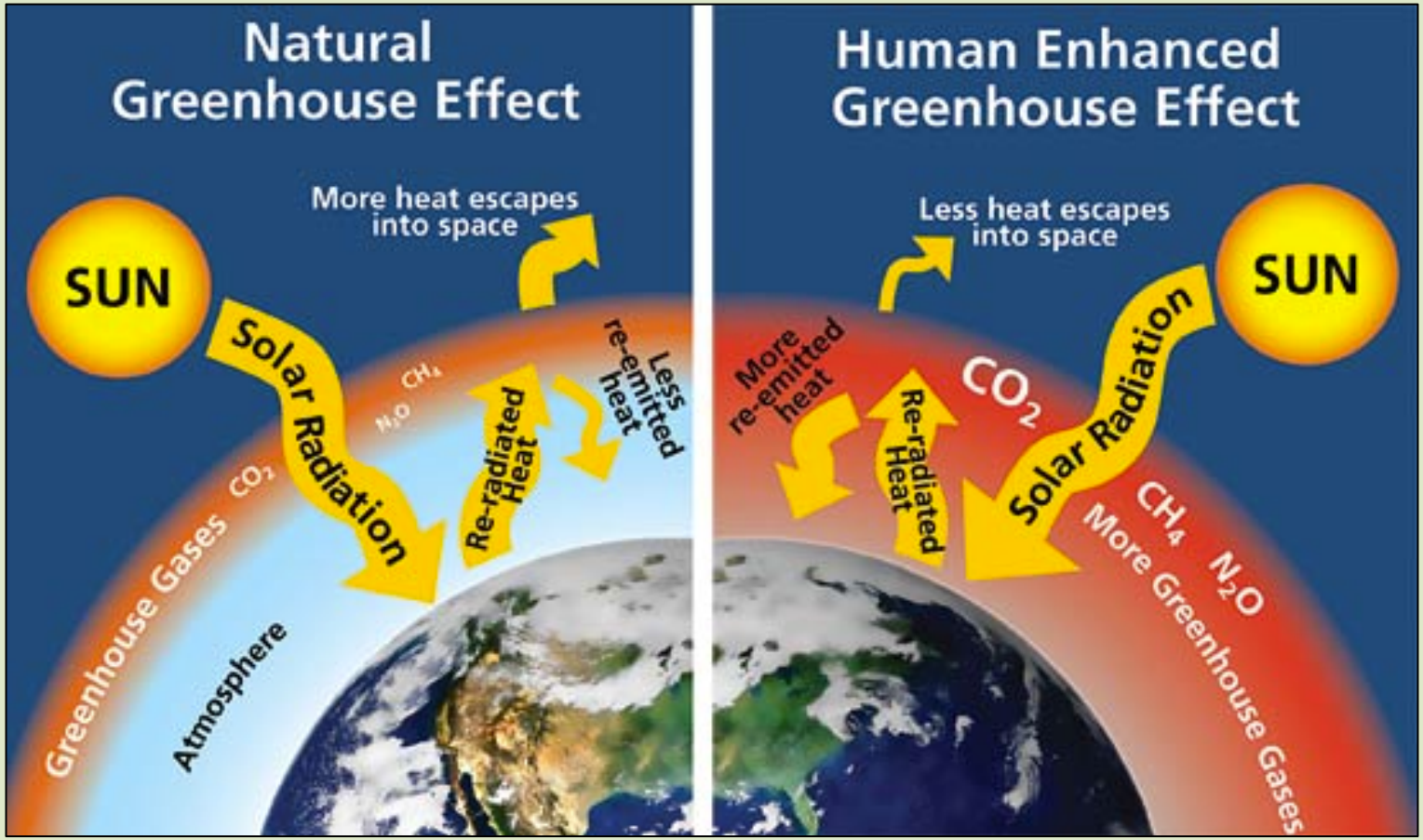
Fossil Fuels Power Our Society

Electricity is generated by burning coal & natural gas to heat water to create high pressure steam that moves a turbine/generator to produce electricity.





Fossil Fuels, Carbon Dioxide, the Greenhouse Effect, Global Warming, & Climate Change



Burning fossil fuels such as coal, oil, and natural gas releases carbon dioxide into our atmosphere. This traps heat in our atmosphere, causing the human enhanced greenhouse effect, which leads to global warming and climate change.

What is Energy?

Energy: The ability to cause change or do work.

The Law of Conservation of Energy

Energy is conserved. Energy may transformed from one form to another but it cannot be created or destroyed.

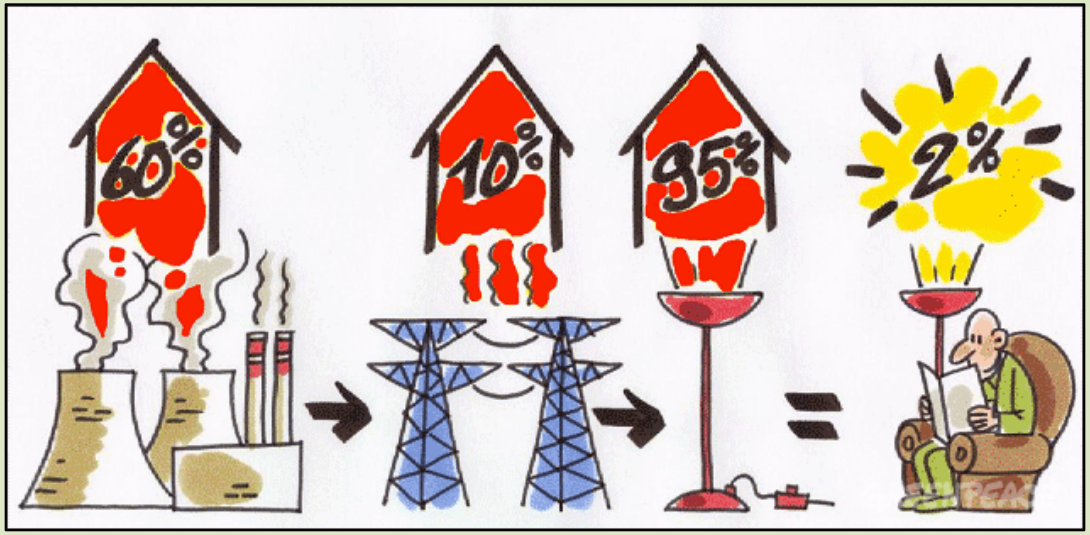
First law of thermodynamics

It takes energy to get energy; It takes energy to pump oil from ground, refine it, and transport it

Second law of thermodynamics

Some high-quality energy is wasted at every step

- i.e. Energy lost as heat at each transfer



What is Energy?

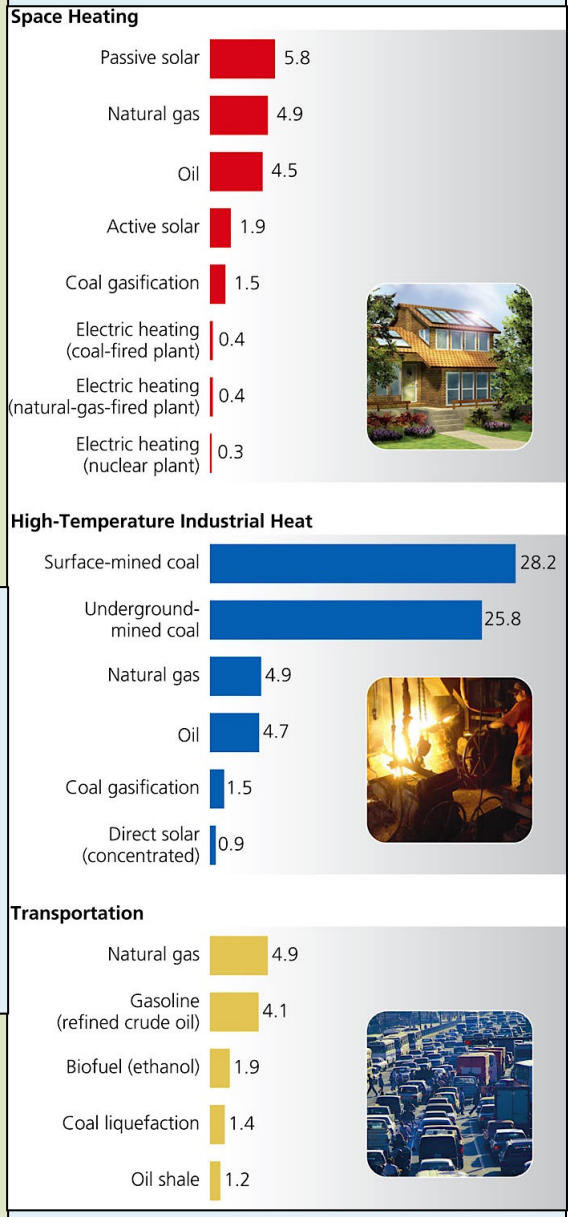
Net energy: total amount of useful energy available from a resource ***minus*** the energy needed to make the energy available to consumers.

Business net profit =
total money taken in minus all expenses

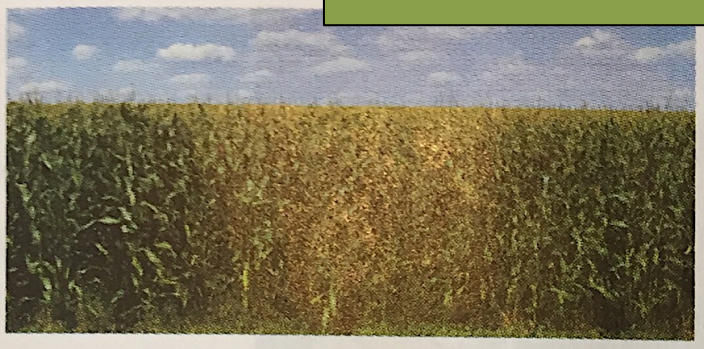
Net energy ratio =
ratio of energy produced ÷ energy used to produce

Example: Suppose it takes 9 units of energy to produce 10 units of energy by growing corn to produce ethanol fuel for cars. The net energy is 1 unit.
The net energy ratio is 10/9 or approx. 1.1.
As the ratio increases the net energy also rises.
When the ratio is less than 1 , there is a net energy loss.

Conventional oil, gas, & coal = high net energy ratio;
i.e. yields lots of heat energy when burned and have traditionally been relatively easy to obtain.



BioFuel: Ethanol Fuel



Outputs

Producing by-products from scratch would require 5,390,000 kJ, so credit is given for these.

Inputs

Growing 0.4 ha (1 acre) of corn requires 8,545,000 kilojoules (kJ).

Break-even point

1,420 L (375 gallons) of ethanol are produced, containing 33,217,000 kJ of energy (a surplus of 3,036,000 kJ).

Converting corn into ethanol and distributing it requires 21,636,000 kJ.

30,181,000 kJ

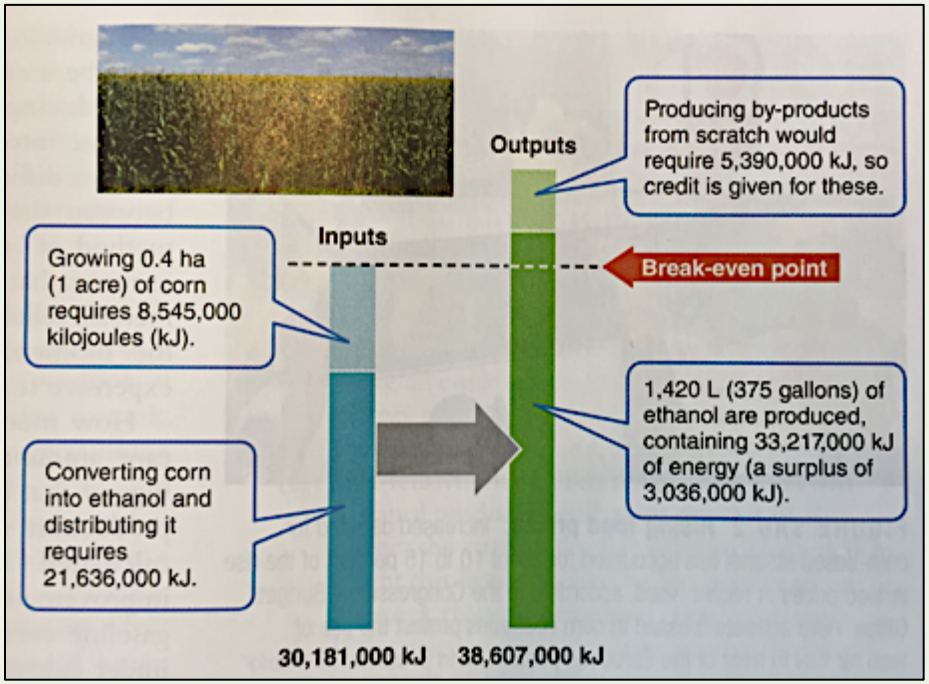
38,607,000 kJ

Energy Required to Produce Ethanol

An analysis of the energy costs of growing and converting 0.4 ha (1 acre) of corn into ethanol shows a slight gain of usable energy when corn is converted to ethanol.

Energy Return On Energy Investment (ER OEI)

The most direct way to account for the energy required to produce a fuel, or energy source, is by calculating the Energy Return On Energy Investment (ER OEI), the amount of energy we get out of an energy source for every unit of energy expended on its production.



$$\text{ER OER} = \frac{\text{Energy obtained from fuel}}{\text{Energy invested to obtain fuel}}$$

$$\frac{38{,}607{,}000\ \text{kJ}}{30{,}181{,}000\ \text{kJ}} = 1.3$$

$$\text{ER OER} = 1.3$$

Should corn be used as an automobile fuel?

Inefficiencies in Energy Use and Transport

Energy Resources With Low or Negative Net Energy Yields Need Marketplace Help

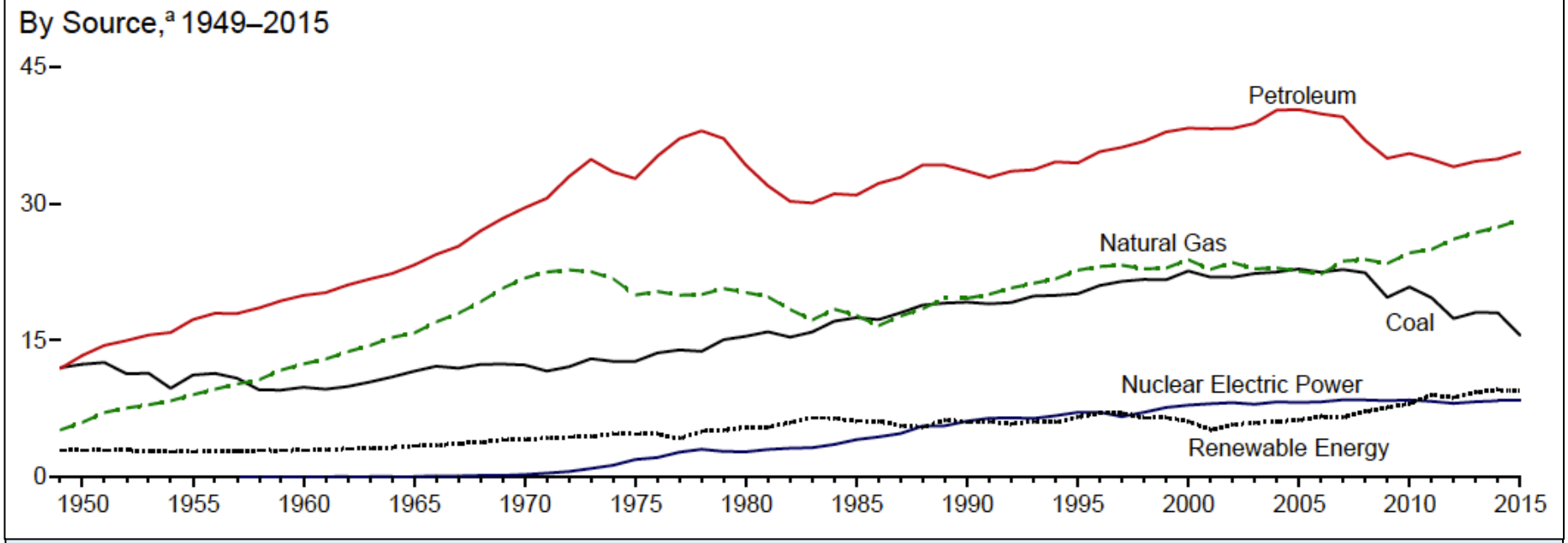
Cannot compete in open markets without government subsidies from taxpayers; e.g. nuclear power + oil and gas industry (to an extent)

Reducing Energy Waste Improves Net Energy Yields & Can Save Money

- 84% of all commercial energy used in the U.S. is wasted
- 43% wasted after accounting for second law of thermodynamics:
  - Inefficient coal burning & nuclear power plants (thermal power plants) produce 2/3^{rds} of electricity in the U.S.
  - Most Americans drive inefficient cars; gas guzzlers with low MPG
  - Most Americans live and work in poorly designed under insulated buildings equipped with energy inefficient appliances.

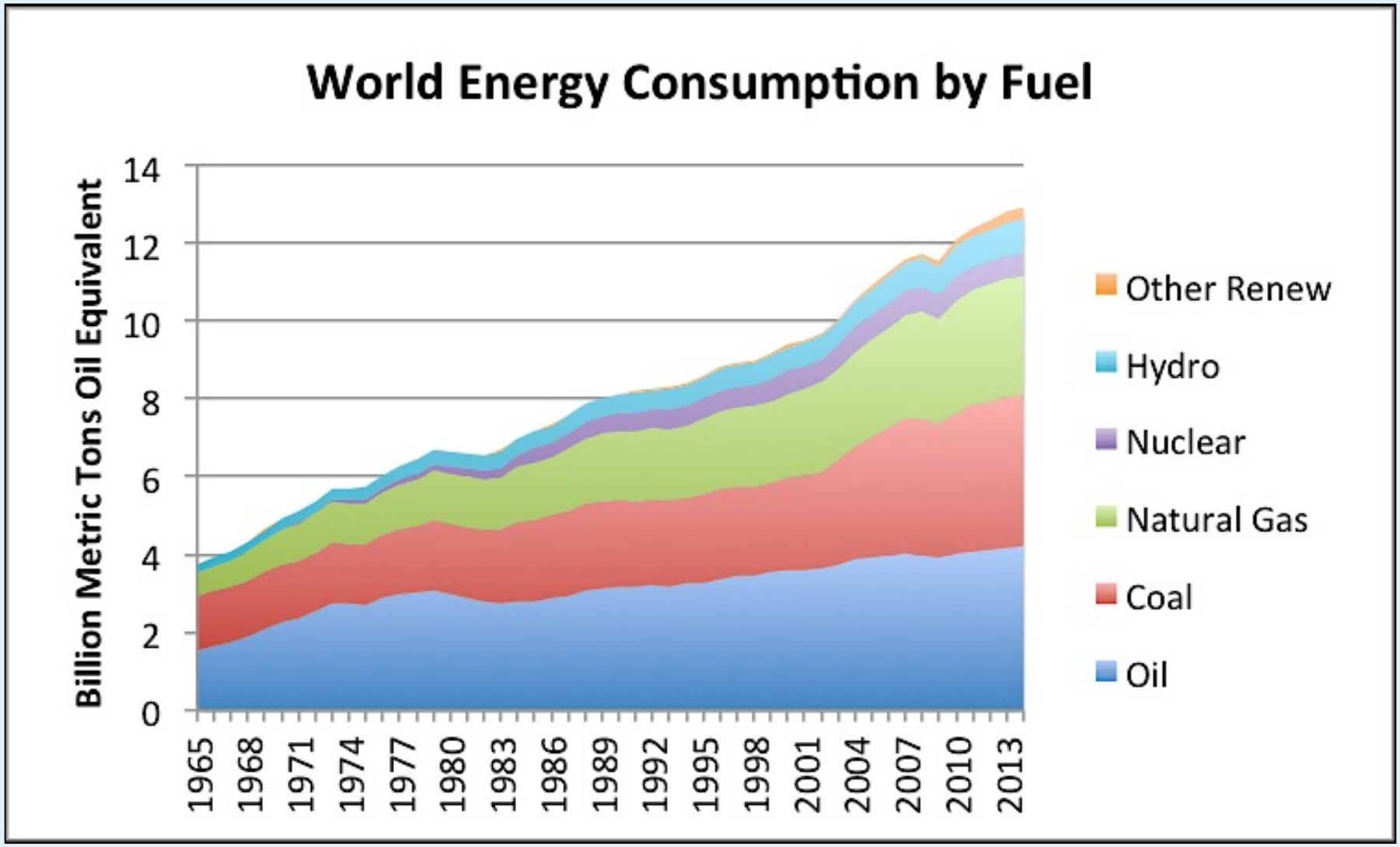
Energy Patterns

Patterns of Energy Use in US- By Fuel Source



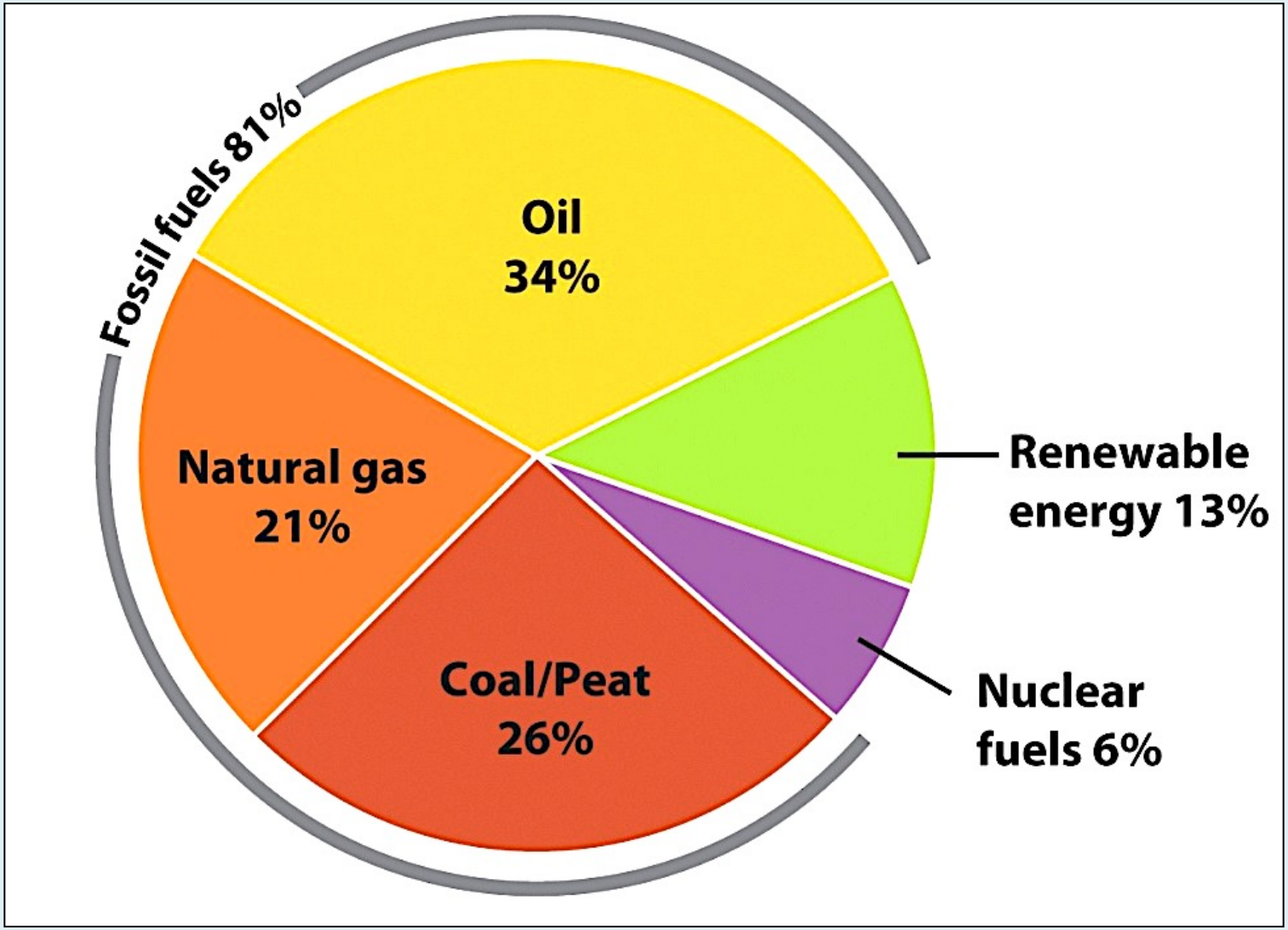
Energy Patterns

Worldwide Patterns of Energy Use- By Fuel Source (2013)

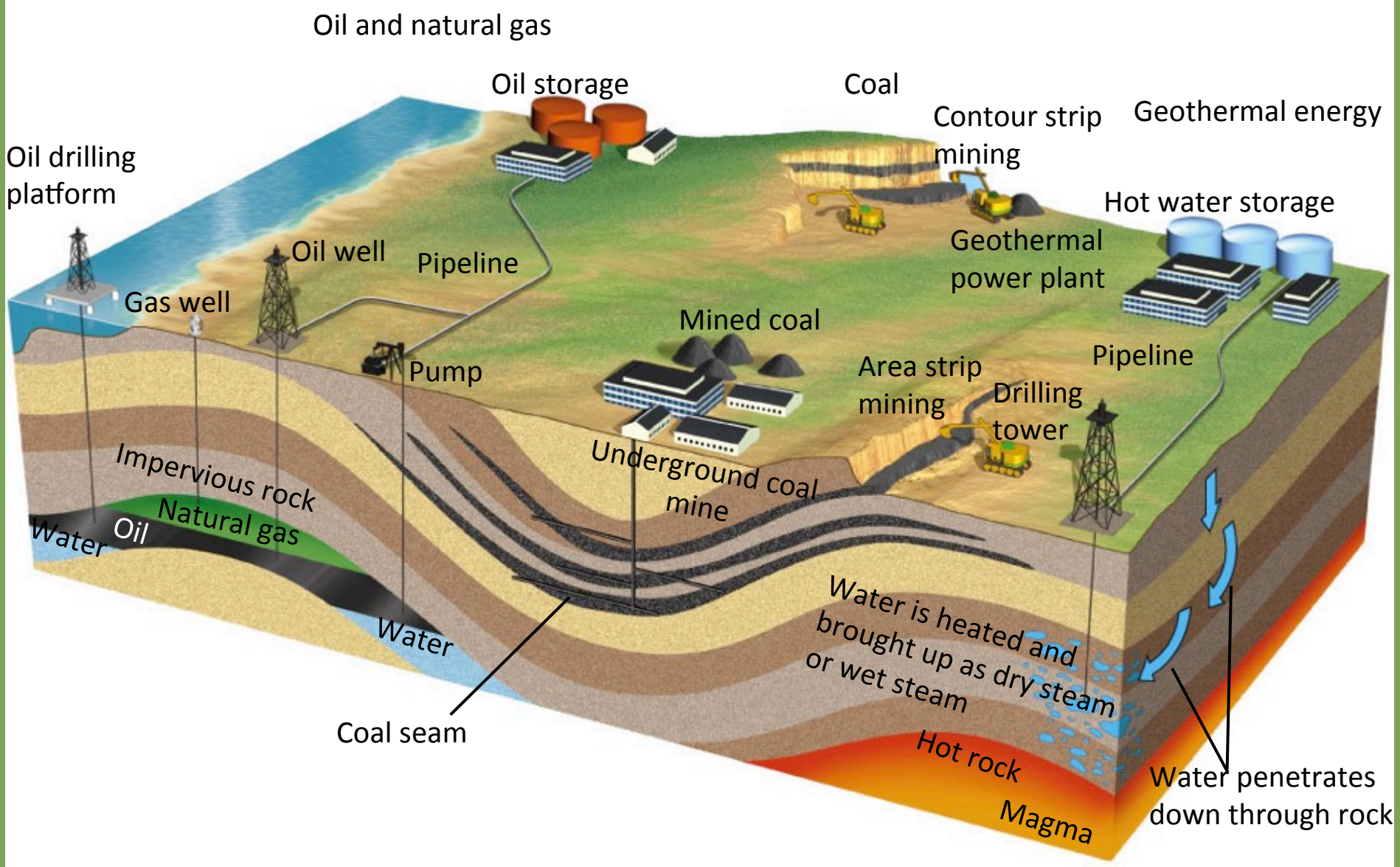


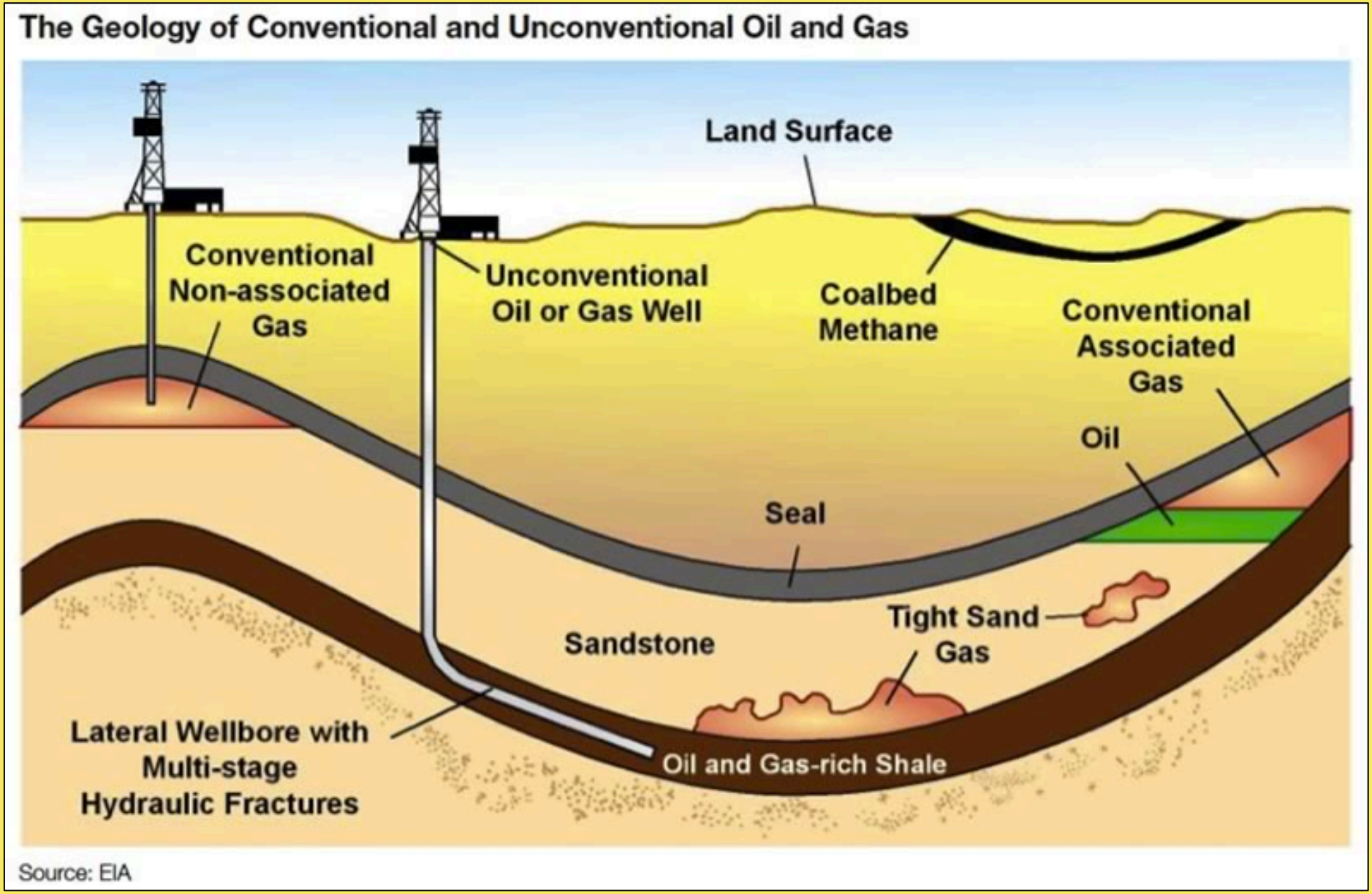
Energy Patterns

Worldwide Patterns of Energy Use- By Fuel Source (2010)

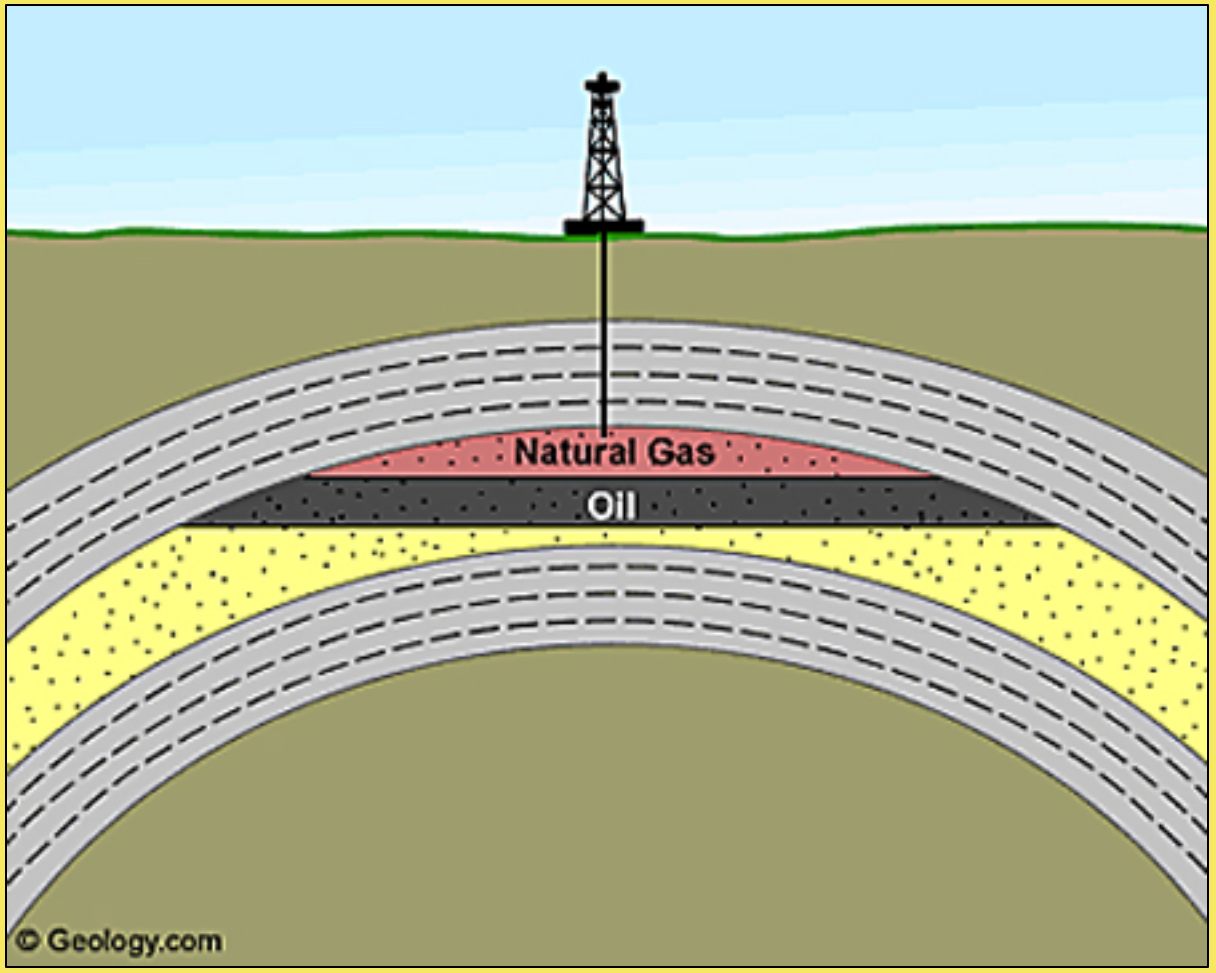


Fossil Fuel Deposits & Extraction




The Geology of Conventional and Unconventional Oil and Gas
Land Surface
Conventional
Non-associated
Gas
Unconventional
Oil or Gas Well
Coalbed
Methane
Conventional
Associated
Gas
Oil
Seal
Tight Sand
Gas
Sandstone
Lateral Wellbore with
Multi-stage
Hydraulic Fractures
Oil and Gas-rich Shale
Source: EIA

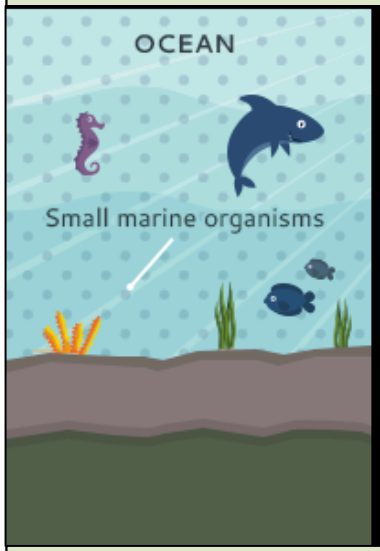
Conventional Oil and Gas Deposit

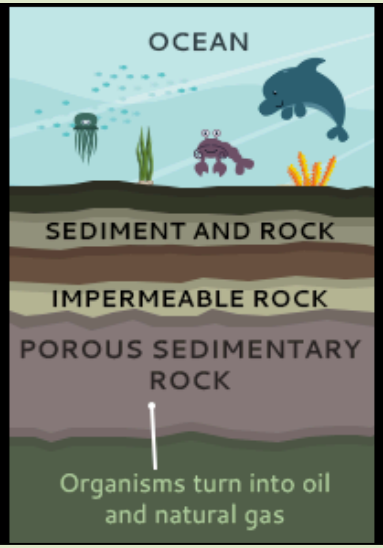


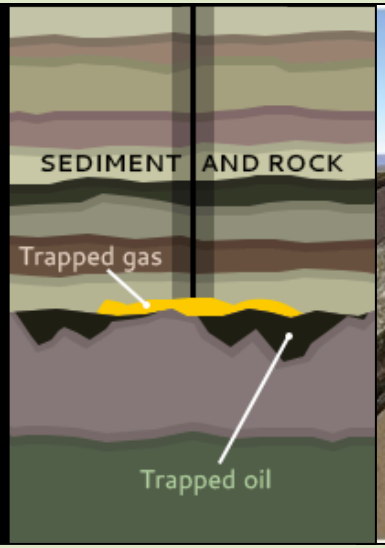
Oil (Petroleum)

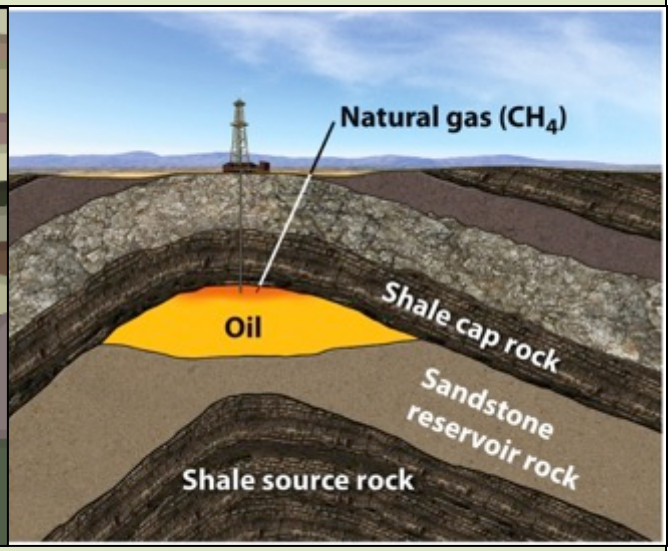
Petroleum i.e. **crude oil**

Fossil fuel formed from remains of ocean-dwelling phytoplankton that died and were deposited 50-150 million years ago; settled into porous sedimentary rock like sandstone capped by nonporous rock.









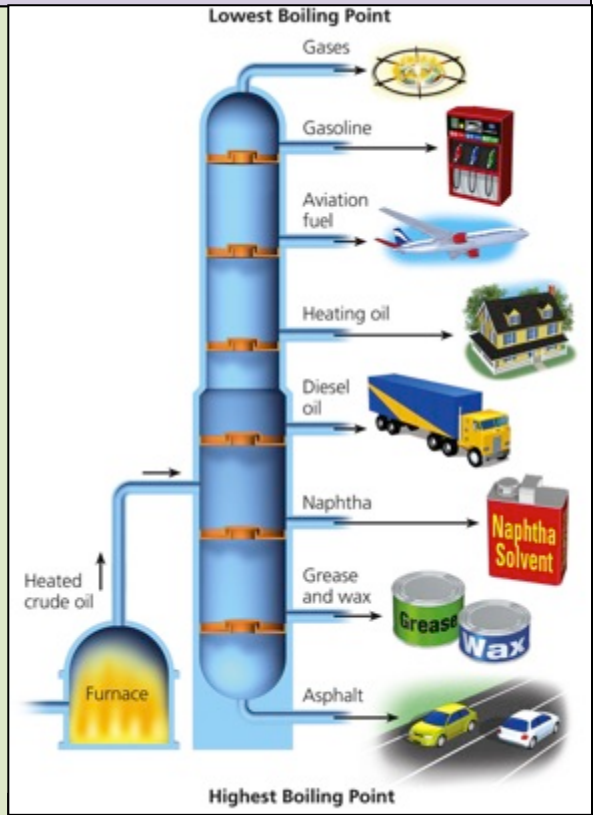
Crude Oil is a mixture of hydrocarbons along with impurities like sulfur and nitrogen. Deposits are usually found with natural gas and located using satellite data, ground surveys, *seismic surveys = computerized 3-D images of earth's interior, and exploratory drilling*. **Conventional oil** is extracted by means of drilling oil wells and pumping out the crude oil.

Conventional Oil (Petroleum)

Petroleum Products Supply Chain & Refineries

After extraction the oil is transported to a refinery by pipeline, truck, or ship.

Crude oil is converted into useful petroleum products at a refinery through a process known as fractional distillation which separates the oil into gasoline, diesel fuel, etc.; settle out based on density and boiling point.



Petrochemicals

Some of the products of crude oil distillation are petrochemicals: raw materials to make ***plastics,*** nylon, paints, & pesticides, etc.

Conventional Oil (Petroleum)

Gasoline & Diesel Fuel

Combustion of gasoline and diesel fuel emits the greenhouse gas carbon dioxide (CO_2); as well as nitrogen oxides (NO_x), and other smog forming pollutants which pose threats to human health.

Oil (Petroleum)

How Long Might Supplies of Conventional Crude Oil Last?

Proven oil reserves

Identified deposits that can be extracted profitably with current technology

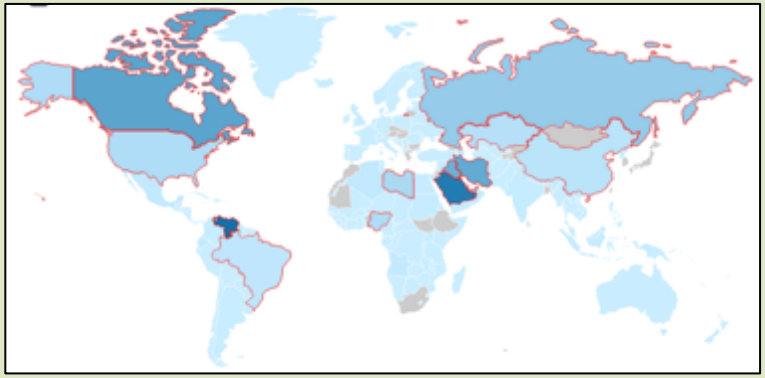
Unproven reserves

Probable reserves: 50% chance of recovery; Possible reserves: 10-40% chance of recovery

Proven and unproven reserves will be 80% depleted sometime between 2050 and 2100

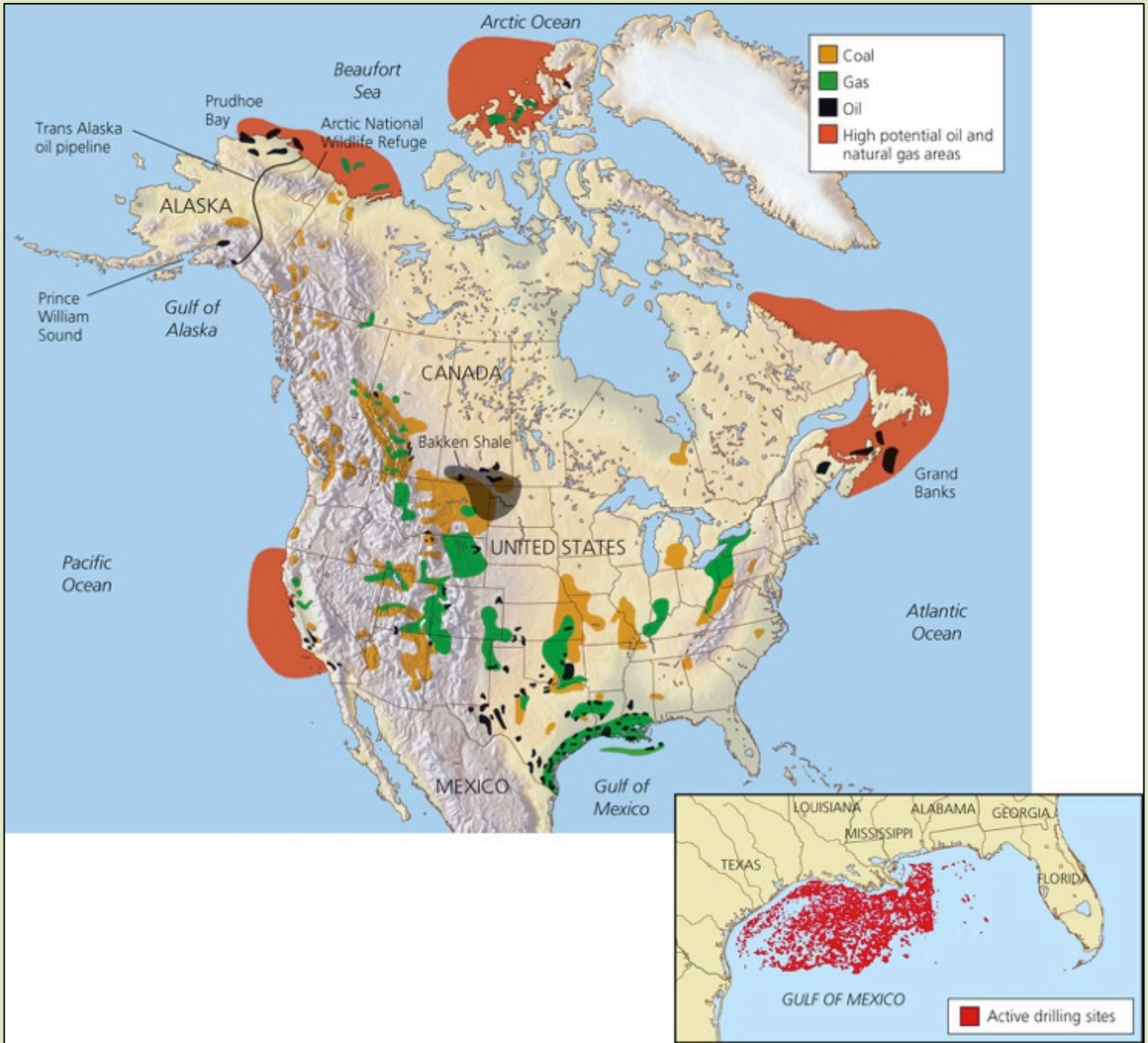
Crude Oil Proved Reserves – 2015

1. Venezuela
2. Saudi Arabia
3. Canada



OPEC: Organization of Petroleum Exporting Countries. 11 countries that have 78% of world's crude oil reserves. Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, **Saudi Arabia**, United Arab Emirates, **Venezuela**.

Proven and Unproven Reserves of Fossil Fuels in North America



Traditional Oil Rig Saudi Arabia

President Obama walks past an oil rig in New Mexico. (2014)

Off-Shore Oil Rig

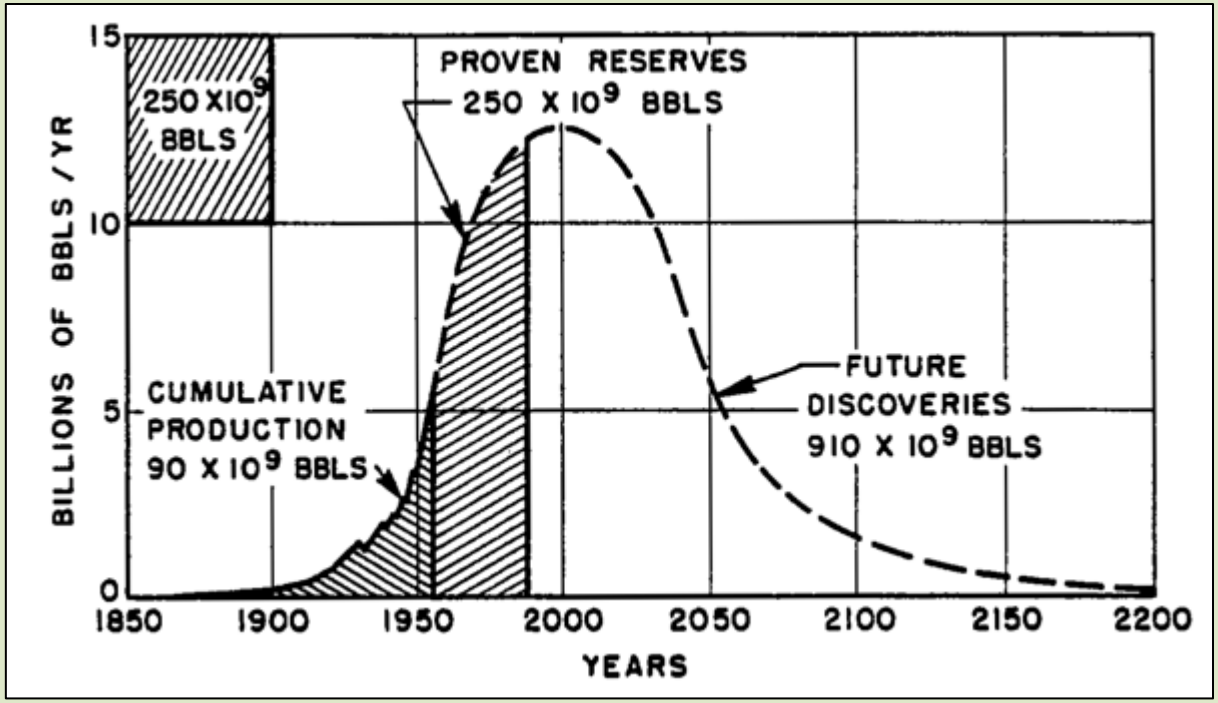
Oil (Petroleum)

How Long Might Supplies of Conventional Crude Oil Last?

Peak Oil: maximum rate of extraction of petroleum is reached, after which it is expected to enter terminal decline.

Hubbert Peak Theory

For any given geographical area, from an individual oil-producing region to the planet as a whole, the rate of petroleum production tends to follow a bell-shaped curve called the the Hubbert curve (Hubbert 1956; Shell Oil).



Oil (Petroleum)

How Long Might Supplies of Conventional Crude Oil Last?

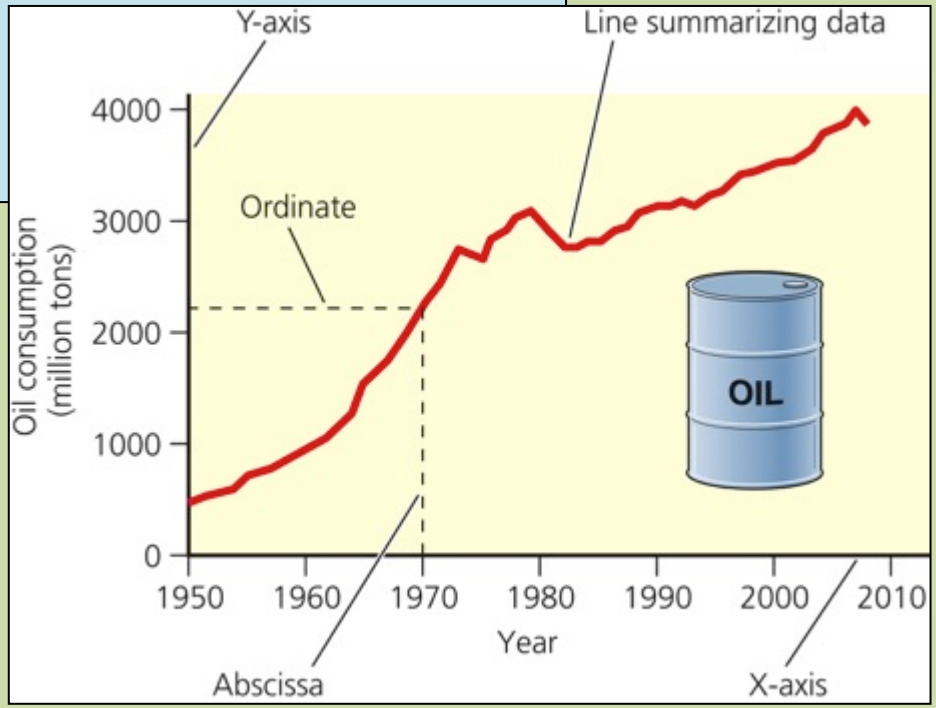
Rapid increase in global oil consumption since 1950. Expected economic depletion within the next 50 years. Many conventional sources are depleted; unconventional sources have opened up more proven reserves; thus extending the lifetime of global oil supplies.

Total Petroleum and Other Liquids Production 2015

1. United States
2. Saudi Arabia
3. Russia

Largest consumers in 2009

1. United States, 23%
2. China, 8%
3. Japan, 6%



Trade-Offs

Conventional Oil

Advantages

Ample supply for several decades

High net energy yield but decreasing

Low land disruption

Efficient distribution system

Disadvantages

Water pollution from oil spills and leaks

Environmental costs not included in market price

Releases CO 2 and other air pollutants when burned

Vulnerable to international supply interruptions

Artic National Wildlife Refuge (ANWR)

ANWR

The largest national wildlife refuge in the United States, the ANWR is located in Northeastern Alaska and consists of 19 million acres (78,000 km^2). The question of whether to drill for oil in the ANWR has been an ongoing political controversy since 1977. Much of the debate rests on the amount of recoverable oil vs. potential harm to wildlife and arctic tundra.

National Petroleum Reserve Alaska (NPRA) & Arctic National Wildlife Refuge (ANWR)

Oil Spill Case Studies

Exon Valdez

Occurred in Prince William Sound, Alaska on March 24, 1989, when the Exxon Valdez oil tanker bound for Long Beach, California, struck Prince William Sound's Bligh Reef.

Spilled 10.8 million gallons of crude oil into Prince William Sound; considered to be one of the most devastating human-caused environmental disasters. The second largest oil spill in US waters, after the 2010 Deepwater Horizon.

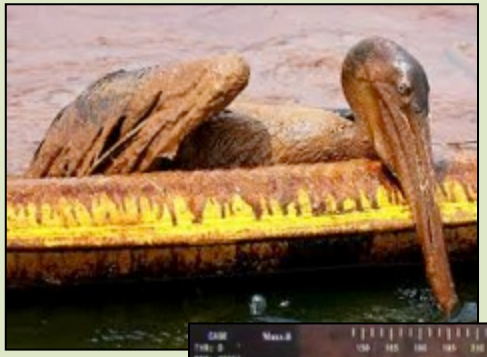
Environmental Problems from Oil Spills in Coastal Areas

- Birds may lose their buoyancy or ability to fly if their feathers are coated with oil;
- Degradation of nursery grounds, feeding grounds, and habitat may lead to loss of biodiversity;
- Food webs may be disrupted when populations of specific organisms in the web are reduced or suffer negative health impacts;
- Organisms may be killed by smothering, or by ingesting, inhaling, or absorbing oil.

Oil Spill Case Studies

Deepwater Horizon

- a.k.a. BP oil spill or Gulf of Mexico oil spill
- Started April 20th 2010 and flowed for 87 days until it was capped;
- Eleven people went missing and were never found;
- Considered the largest accidental marine oil spill in the history of the petroleum industry.



Cleaning Up an Oil Spill

Cleanup workers first surround the slick with **floating booms** to keep it from spreading to harbors, beaches or biologically important areas like marshes. Then they can use different tools to remove the collected oil. Often they will drive **skimmers**, boats that skim spilled water from the water's surface, through the slick.

After most of the oil is removed by skimmers, workers use **sorbents**; Sorbents to either absorb oil like a sponge or adsorb oil, which means that oil sticks to its surface.

Biological methods: introduce bacteria that breaks down oil.

Dispersants are chemicals that break down the oil into smaller particles that mix with water more easily; this allows natural bacteria and evaporation to break down the oil more easily.

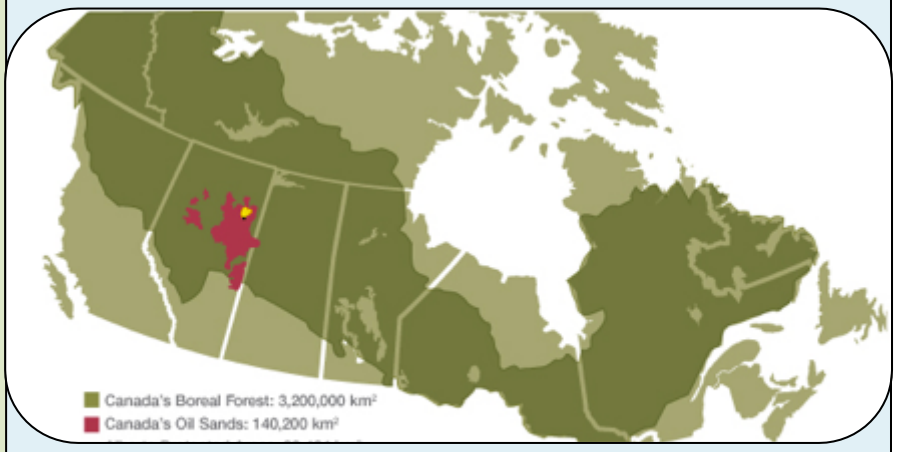
Combustion: burning the oil off the surface of the ocean.

Chemical dispersants are toxic and enter the base of the food chain (zooplankton/ phytoplankton), bioaccumulate, and potentially harm wildlife.

Unconventional Oil: Tar Sands

Tar Sands

- a.k.a oil tar or ***oil sand;***
- Tar sand contains the hydrocarbon called ***bitumen***;
- It is a mixture of clay, sand, water and bitumen (thick heavy oil with high sulfur content).
- Strip mined using massive machines called draglines;
- Then, massive haul trucks transport it to refineries where hot water & steam are used to extract bitumen.
- Found mostly in Canada; also Venezuela.
- Moderate net energy yield since energy is required for, blasting, drilling, crushing, heating the material, disposing of waste material, & land restoration.



Unconventional Oil: Tar Sand

Tar Sands

- *In situ* methods—pumping high pressure steam into underground deposits—can be used, which does not degrade land, but has potential to affect aquifers.
- Cost per barrel higher than conventional oil due to high energy investment.
- **Severe environmental impact**: clearing of boreal forest (one of the worlds largest remaining carbon sinks), habitat loss, uses and contaminates large volume of water, creates toxic sludge that must be stored in massive containment ponds, requires energy inputs i.e. natural gas that reduces net energy yield; *2 tons of oil sand for 1 barrel of oil.*

Unconventional Oil: Tar Sand

Keystone Pipeline

A proposed 1,179-mile pipeline that would transport as much as 830,000 barrels of synthetic crude and diluted bitumen each day to Nebraska and then to refineries along the Gulf Coast of Texas. Pipeline crosses the Ogallala Aquifer, a vast groundwater reservoir that provides irrigation water to the U.S.'s largest agricultural region. A pipeline burst and an oil spill there could contaminate this vital resource. Pipelines do burst; in 2010 a pipeline transporting tar sands crude burst and spilled more than a million gallons of oil into the Kalamazoo River in Michigan.

Unconventional Oil: Oil Shale

Oil Shale

- Oil shale contains the hydrocarbon ***kerogen***.
- When oil shale is heated in the absence of air, the kerogen converts to oil.
- Oil shale is extracted through strip-mining or *in situ* methods just as tar sands and have a similar environmental impact.
- Of the 3 trillion barrels of recoverable oil from shale in the world, 750 billion are located in the U.S; with most being located in the Green River Formation in Wyoming, Colorado, and Utah.
  - Oil locked up in rock
  - Arid western states lack of water needed for extraction and processing
  - Low net energy yield

Trade-Offs

Heavy Oils from Oil Shale and Tar Sand

Advantages

Large potential supplies

Easily transported within and between countries

Efficient distribution system in place

Disadvantages

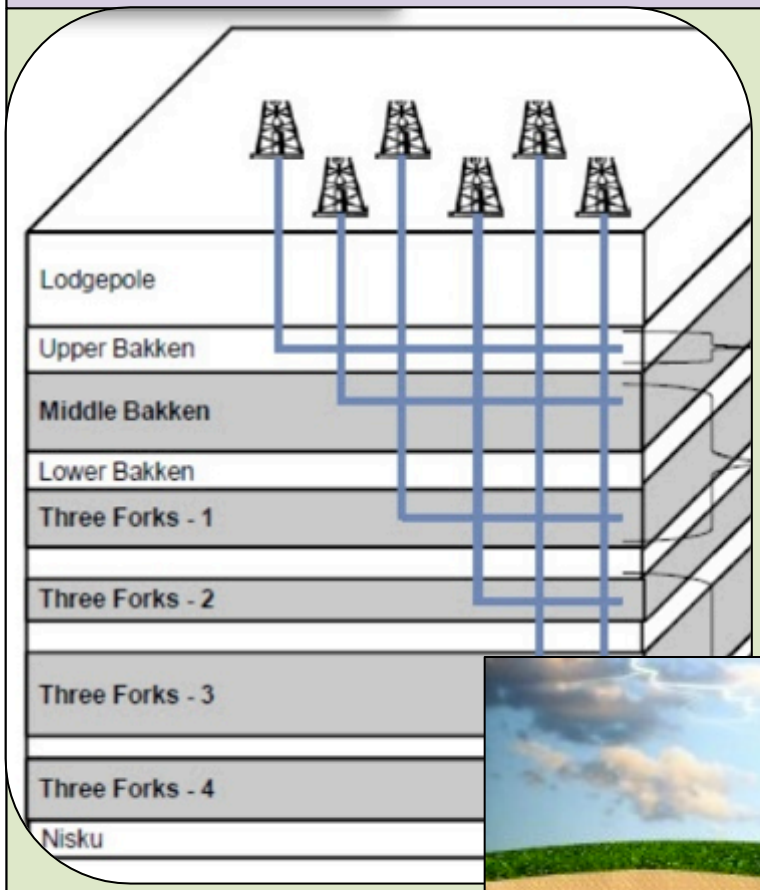
Low net energy yield

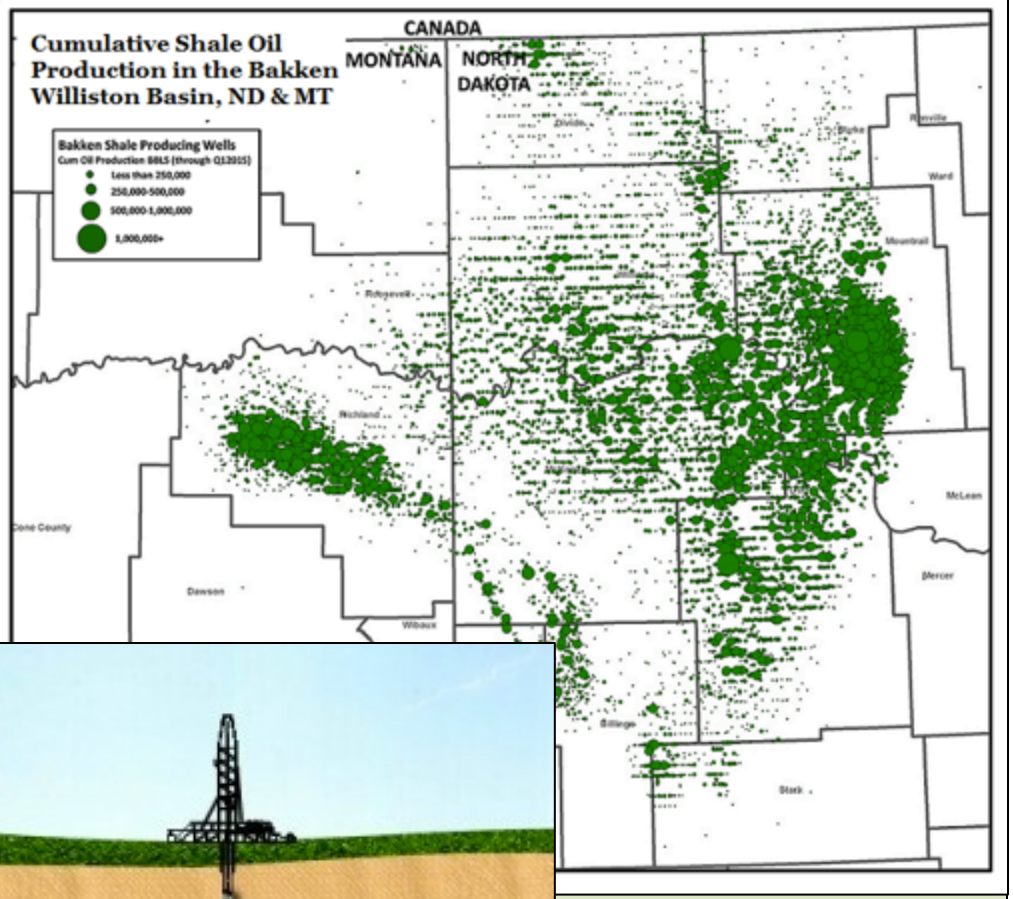
Releases CO 2 and other air pollutants when *produced* and *burned*

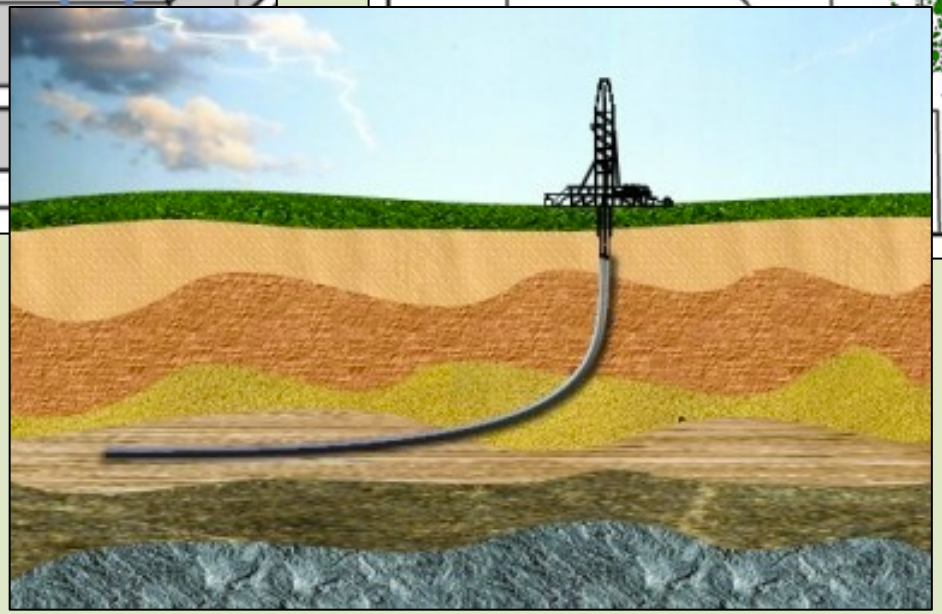
Severe land disruption and high water use

Clearing of carbon sequestering boreal forests

Unconventional Oil: Hydraulic Fracturing- Bakken Formation







Unconventional Oil: Hydraulic Fracturing- Bakken Formation

The Bakken Oil Fields

- The Bakken Formation contains many layers of shale oil and gas as deep as 11,000 ft.
- One of the largest contiguous deposits of oil and natural gas in the United States; underlies large areas of northwestern North Dakota and northeastern Montana.
- Uses directional drilling i.e. "horizontal drilling" and *hydraulic fracturing* i.e. "**fracking**"
- Subsurface rock units such as the Bakken's organic shale formations are saturated with large amounts of oil and natural gas that will not flow freely.
- The hydraulic fracturing process solves this problem by drilling a well into the rock and pumping water under high pressure into that portion of the well, this generating fractures. This water is treated with chemicals and sand. The water and chemicals loosen up the oil and the sand fills in and props open the fractures while being porous enough to allow the oil to flow and be pumped to the surface.

Unconventional Oil: Hydraulic Fracturing- Bakken Formation

Train Derailments and Oil Spills

14 Bakken oil train derailments between July 2013 & June 2016

A train carrying 3 million gallons of North Dakota crude derailed during a snowstorm Feb. 16, 2015, sparking a massive fireball near Mount Carbon, West Virginia. Firefighters had little choice but to let the tanks burn themselves out, which took nearly a week.

A multi-car derailment April 30, 2014, in Lynchburg, Virginia, spilled nearly 30,000 gallons of oil into the James River.

Unconventional Oil: Hydraulic Fracturing- Bakken Formation

Dakota Access Pipeline

Energy Transfer Partner's Dakota Access Pipeline is 60% complete. It was originally supposed to cross the Missouri River near Bismarck, but it was moved due to concerns that an oil spill at that location would contaminate the state capital's (Bismarck, ND) drinking water.

The Standing Rock Sioux oppose the pipeline's construction—which was moved to a location near the Sioux reservation—on the grounds that it threatens their water supply, public health, and cultural resources.

Unconventional Oil: Hydraulic Fracturing- Bakken Formation

Dakota Access Pipeline

The Standing Rock Sioux maintains that the government did not properly consult with them prior to shifting the pipeline's route, which would pass under the Missouri River (at Lake Oahe) just a half a mile upstream from the Tribe's reservation boundary.

What began as a small protest camp on the Standing Rock reservation, has since morphed into an encampment with over 1,000 people.

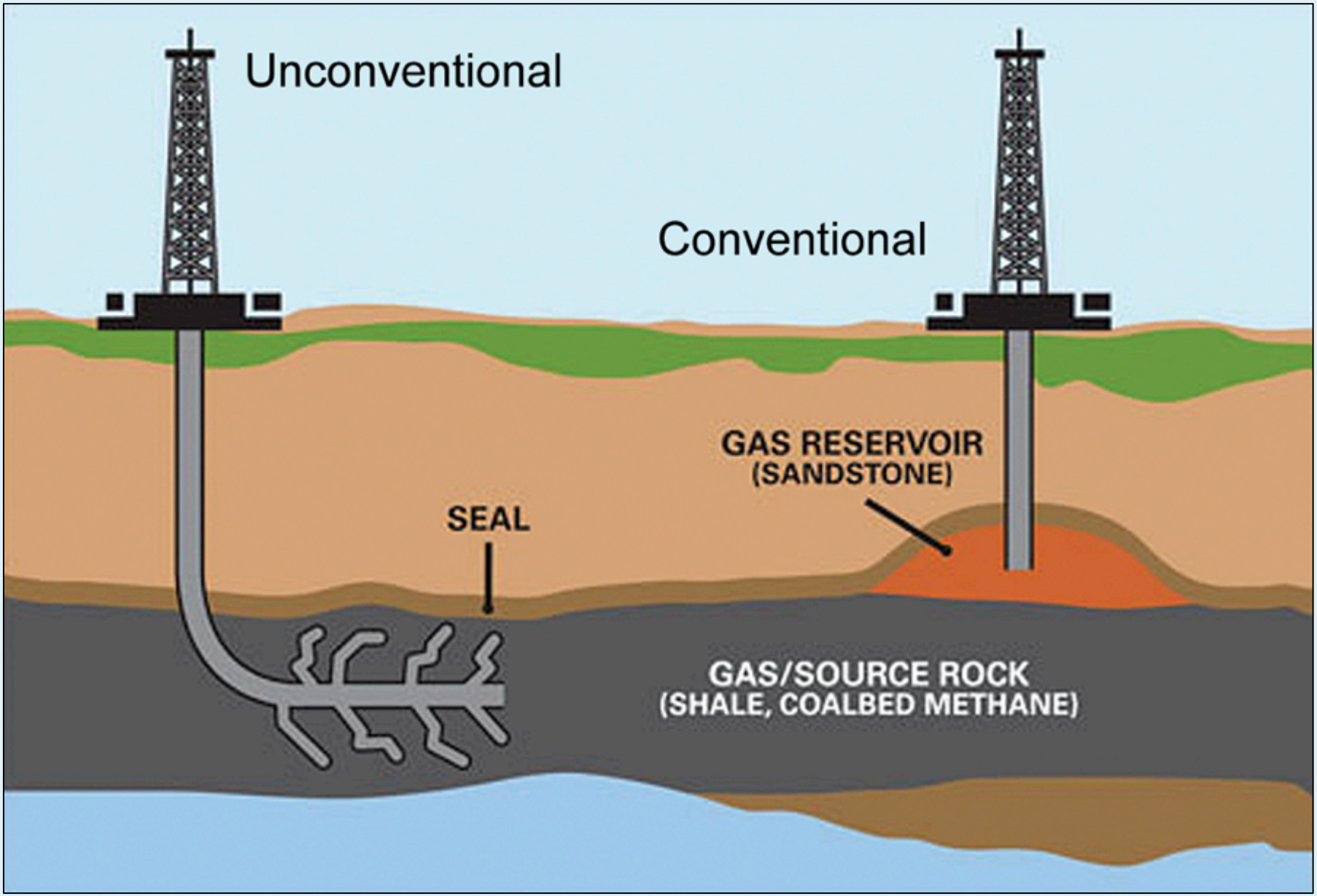
In December 2016, the Obama administration effectively halted the pipeline's construction on all lands of significance to the Standing Rock Sioux.

Summary: Conventional Oil & Unconventional Heavy Oil

Conventional oil is currently abundant, has a high net energy yield, and is relatively inexpensive, but using it causes air and water pollution and releases greenhouse gases to the atmosphere.

Heavy oils from tar sand and oil shale exist in large supplies but have low net energy yields and higher environmental impacts than conventional oil has.

Conventional vs. Unconventional Natural Gas



Conventional Natural Gas

Natural Gas

A mixture of gases; 50-90% is **methane** (CH_4)

Natural gas was formed from the same geologic processes that formed crude oil and is found above most crude oil reservoirs.

Conventional natural gas typically flows from wells under its own pressure.

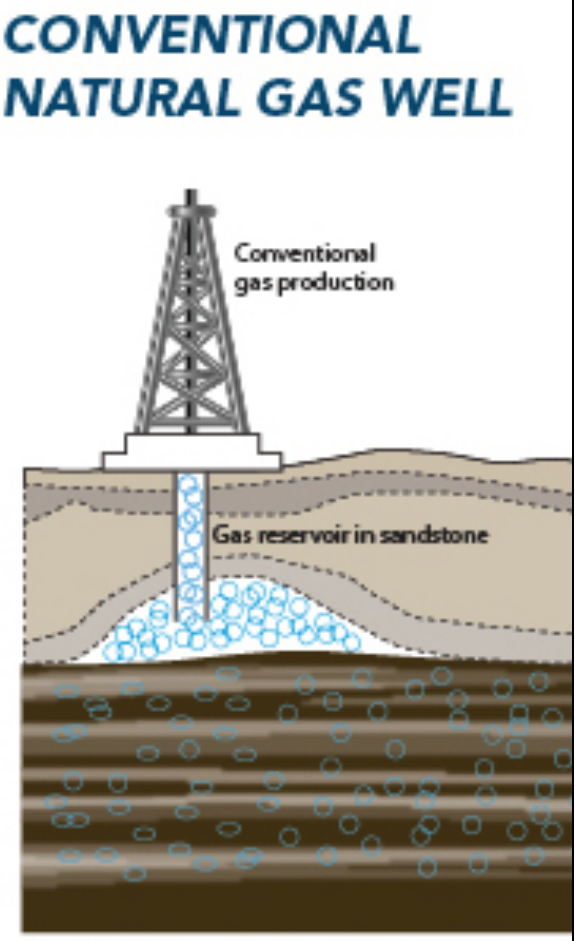
Natural gas is transported from the wellhead to processing facilities through a system of pipelines.

At a processing facility natural gas may be liquefied and trucked to be sold for residential, commercial, and industrial uses;

Liquefied natural gas (LNG).

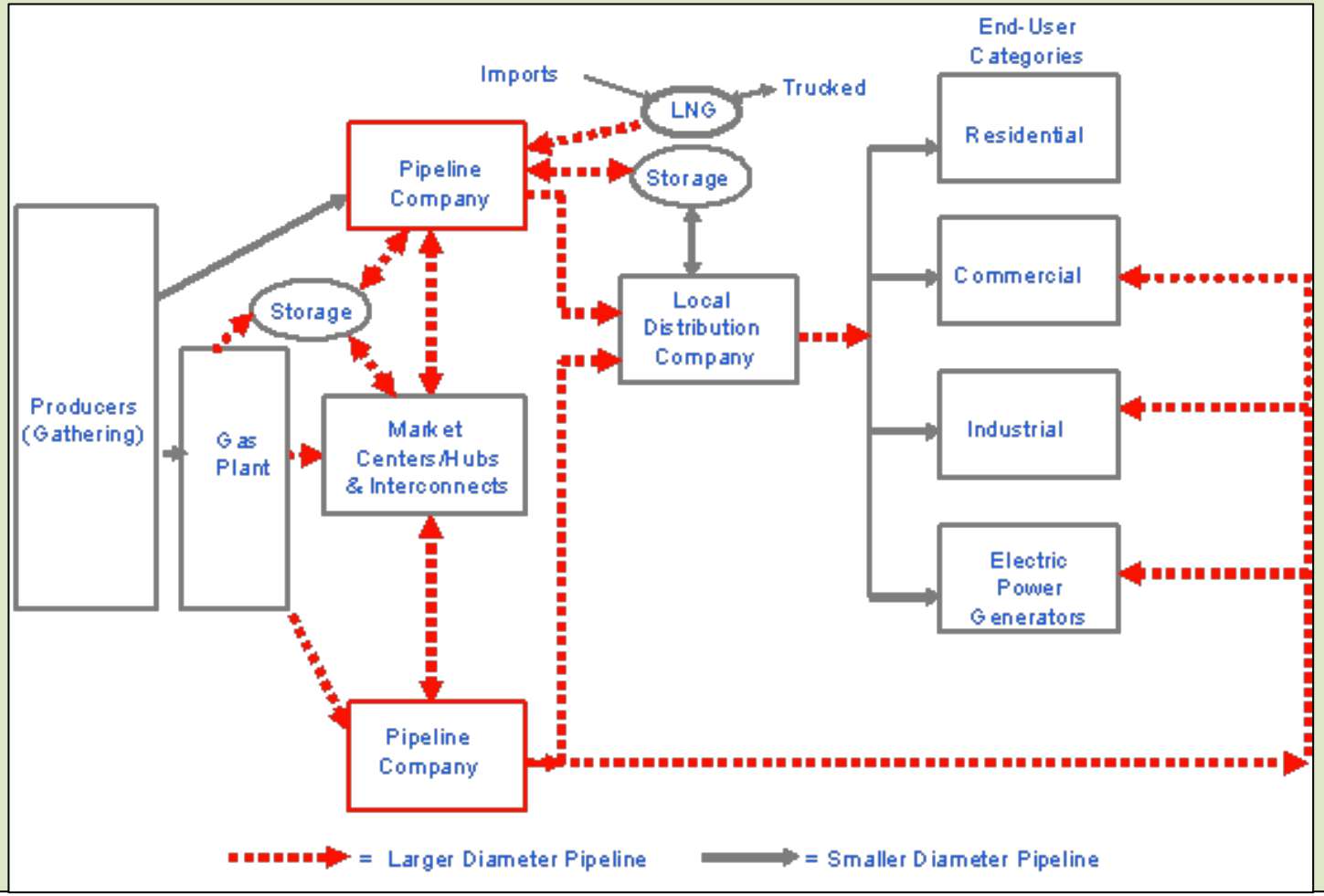
Propane and butane are removed and liquefied; *Liquefied Petroleum Gas (LPG).*

Liquefying natural gas lowers the net energy yield



Natural Gas Supply Chain

Natural gas is transported from the wellhead to the final customer through pipelines. A natural gas pipeline system begins at the natural gas wellhead. Once the gas leaves the well, a pipeline gathering system directs the flow either to a natural gas processing plant or directly to the mainline transmission grid, depending upon the initial quality.



Conventional Natural Gas

Natural Gas

Natural gas is a clean burning fossil fuel, why?

- Relatively free of impurities such as: nitrogen, sulfur, & mercury

Compare the combustion reactions:

Methane (natural gas)

- $2\ CH_4 + 4\ O_2 \rightarrow \mathbf{2\ CO_2} + 4\ H_2O$

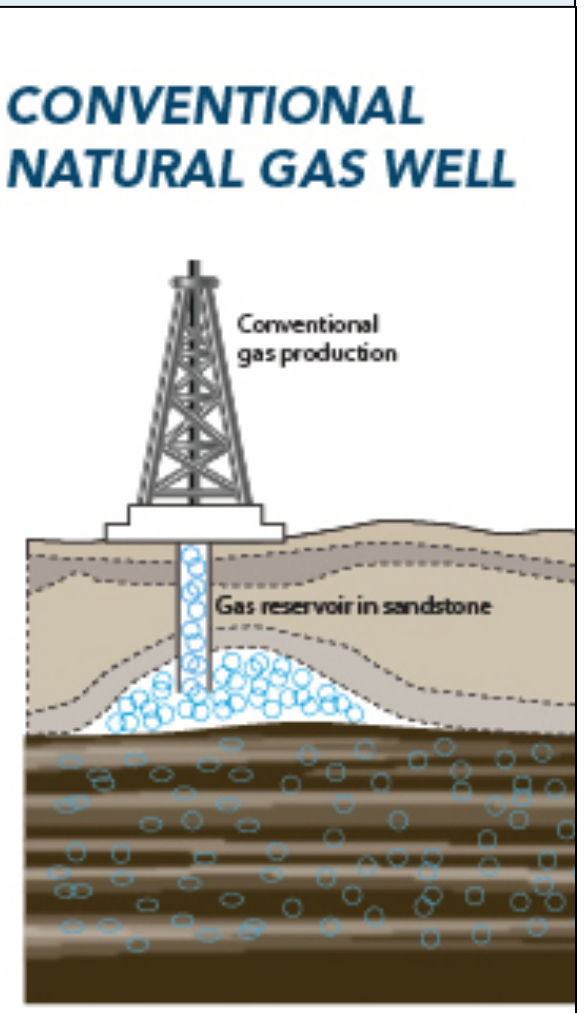
Octane (gasoline)

- $2\ C_8H_{18} + 25\ O_2 \rightarrow \mathbf{16\ CO_2} + 18\ H_2O$

Which fuel yields the less carbon dioxide?

Summary: Conventional Natural Gas

Conventional natural gas is more plentiful than oil, has a high net energy yield and a fairly low cost, and has the lowest environmental impact of all fossil fuels.



Trade-Offs

Conventional Natural Gas

Advantages

Ample supplies

High net energy yield

Emits less CO_2 and other pollutants than other fossil fuels

Disadvantages

Low net energy yield for LNG

Releases CO_2 and other air pollutants when burned

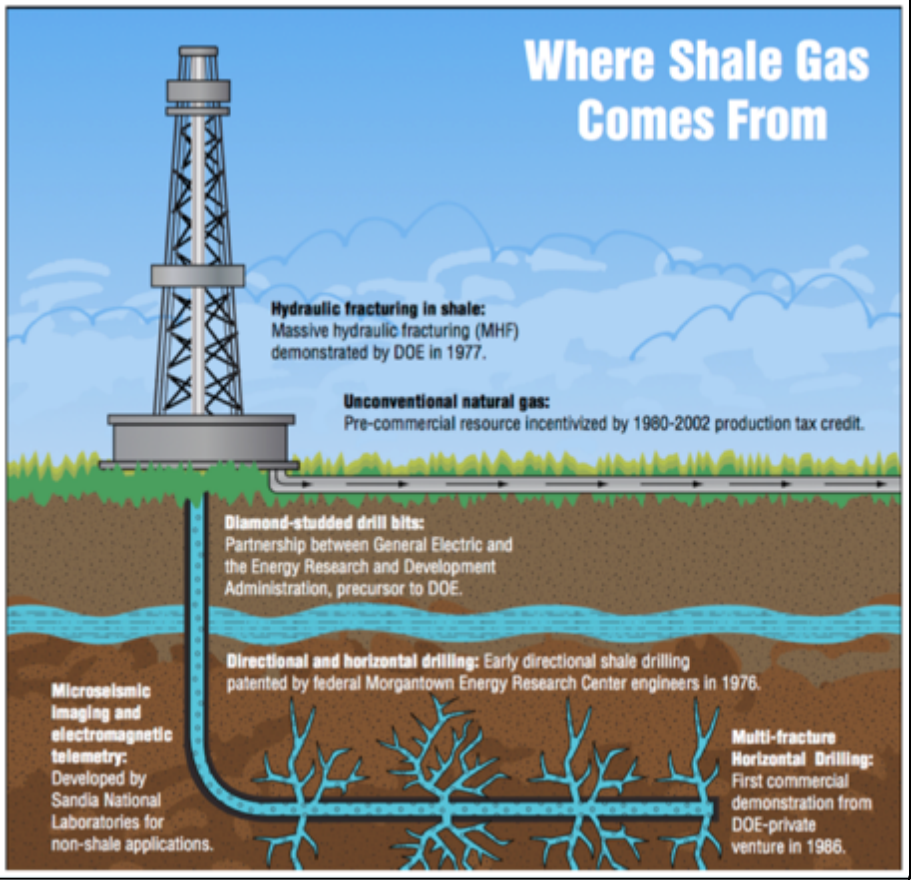
Difficult and costly to transport from one country to another

Methane is a potent greenhouse gas; unburned methane leaks from wells or processing facilities pose a serious threat, in terms of global warming

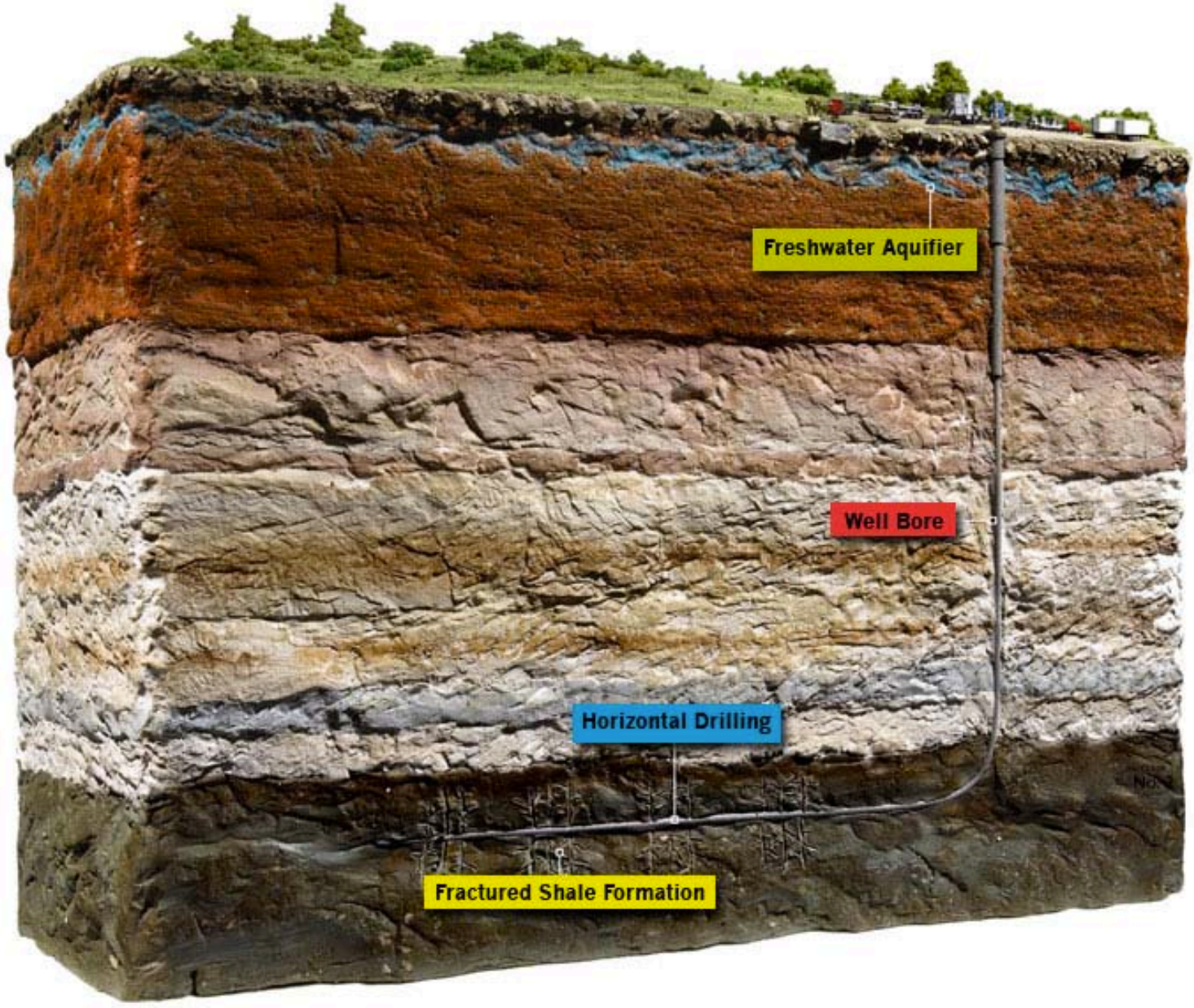
Unconventional Natural Gas: Hydraulic Fracturing "Fracking"

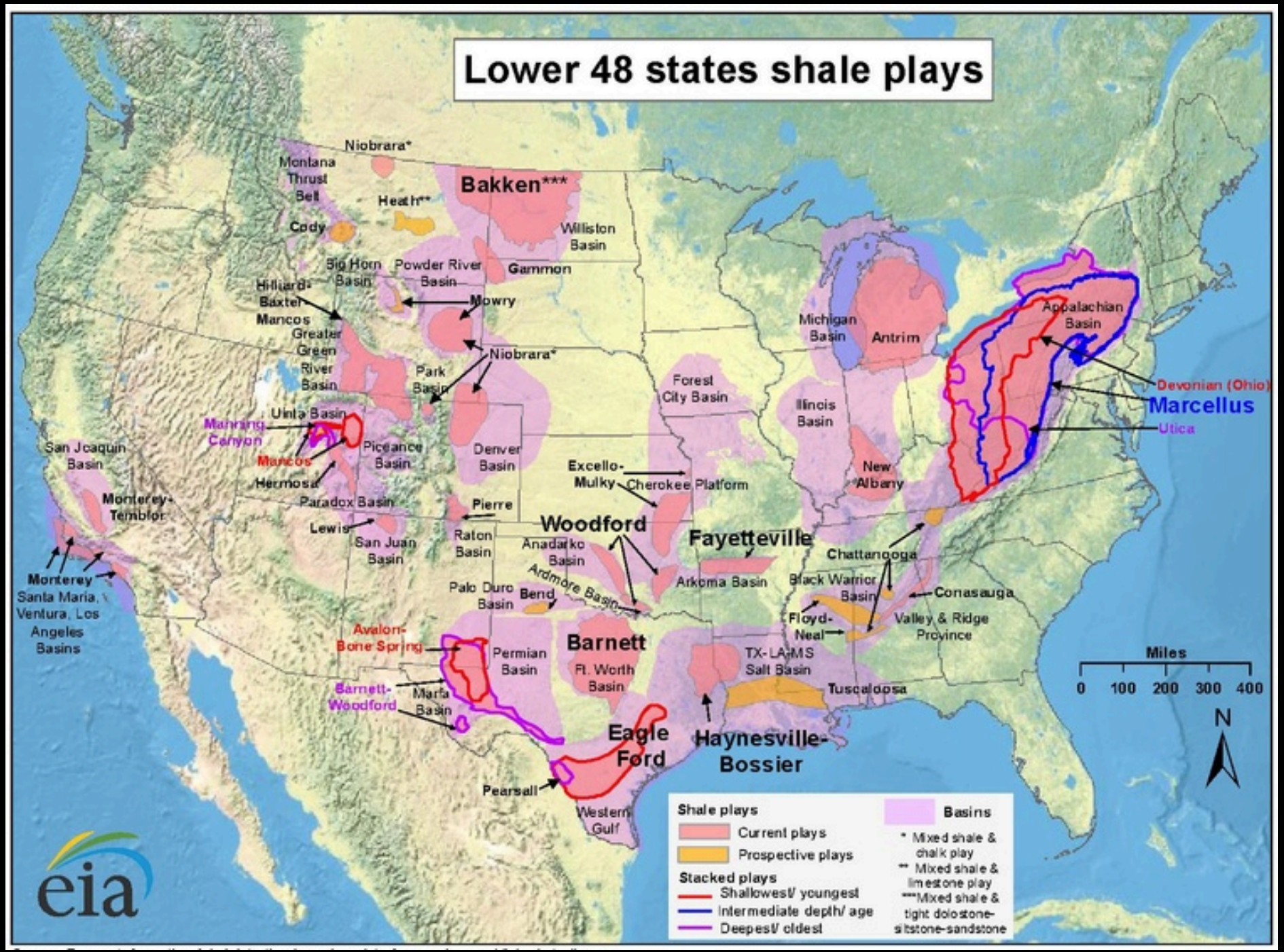
Natural gas is extracted through a combination of *directional drilling* i.e. *"horizontal drilling"* and *hydraulic fracturing* i.e. "**fracking**".

In hydraulic fracturing, chemicals are mixed with large quantities of water and sand and injected into wells at extremely high pressure to create fractures in rock that allow oil and natural gas to escape and flow out of the well.



Unconventional Natural Gas: Hydraulic Fracturing “Fracking”




Lower 48 states shale plays
Niobrara*
Montana Thrust Belt
Heath**
Bakken***
Cody
Williston Basin
Big Horn Basin
Powder River Basin
Gammon
Hilliard-Baxter-Mancos
Mowry
Greater Green River Basin
Niobrara*
Park Basin
Forest City Basin
Michigan Basin
Antrim
Appalachian Basin
Devonian (Ohio)
Marcellus
Utica
Illinois Basin
Uinta Basin
Mahogany Canyon
Mancos
Piceance Basin
Denver Basin
San Joaquin Basin
Hermosa
Paradox Basin
Excello-Mulky
Cherokee Platform
New Albany
Monterey-Temblor
Pierre
Lewis
San Juan Basin
Raton Basin
Woodford
Anadarko Basin
Fayetteville
Chattanooga
Arkoma Basin
Black Warrior Basin
Conasauga
Ardmore Basin
Palo Duro Basin
Bend
Floyd-Neal
Valley & Ridge Province
Monterey
Santa Maria, Ventura, Los Angeles Basins
Avalon-Bone Spring
Permian Basin
Barnett
Ft. Worth Basin
TX-LA-MS Salt Basin
Tuscaloosa
Barnett-Woodford
Marfa Basin
Eagle Ford
Haynesville-Bossier
Pearsall
Western Gulf
Miles
0 100 200 300 400
N
Shale plays
Current plays
Prospective plays
Stacked plays
Shallowest/ youngest
Intermediate depth/ age
Deepest/ oldest
Basins
* Mixed shale & chalk play
** Mixed shale & limestone play
*** Mixed shale & tight dolostone-siltstone-sandstone
eia

Trade-Offs

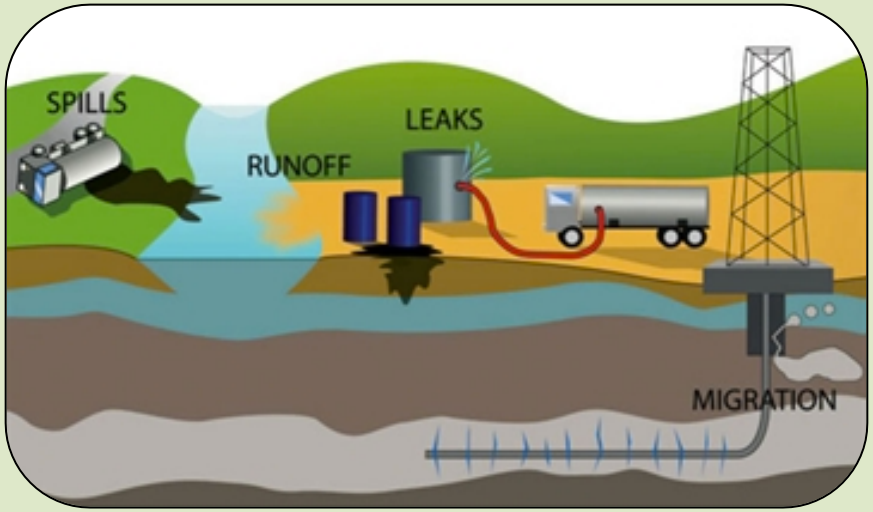
Unconventional Natural Gas: Hydraulic Fracturing

Advantages

Short well construction time; after which 20-40 years of gas production

Technology opens-up new possibilities for gas production

Greater independence from foreign energy sources, creates jobs, stimulates economy



Disadvantages

Dangerous chemicals are used in the process and can enter the water table

Toxic, radioactive, and caustic liquid waste by-products pose storage, treatment, and disposal problems

There are few adequate safeguards or regulations currently in place for this process

Hydraulic fracturing results in contaminated water supplies, air pollution, destroyed streams, and negative environmental impacts on local flora and fauna

→ ***Could frack fluid eventually migrate to groundwater supplies?***

Natural Gas

Excel Energy's Cherokee Generating Station (Denver)

Cherokee was built as a coal-fired plant, but has undergone a complete makeover as part of Colorado Clean Air-Clean Jobs legislation.

Excel energy built pipeline from Weld County to deliver gas for Cherokee.

Excel Energy's Cherokee Generating Station; 64th and Washington Denver, CO

Natural Gas

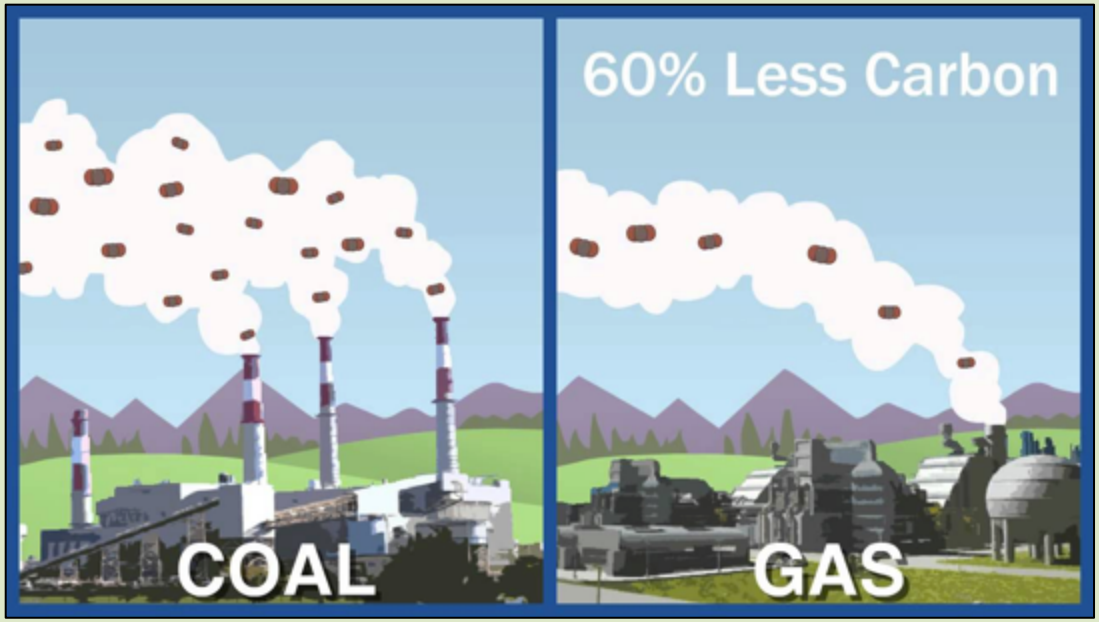
Excel Energy's Cherokee Generating Station (Denver)

A new natural gas combined cycle plant went online in 2015, capable of producing almost 580 megawatts of cleaner energy.

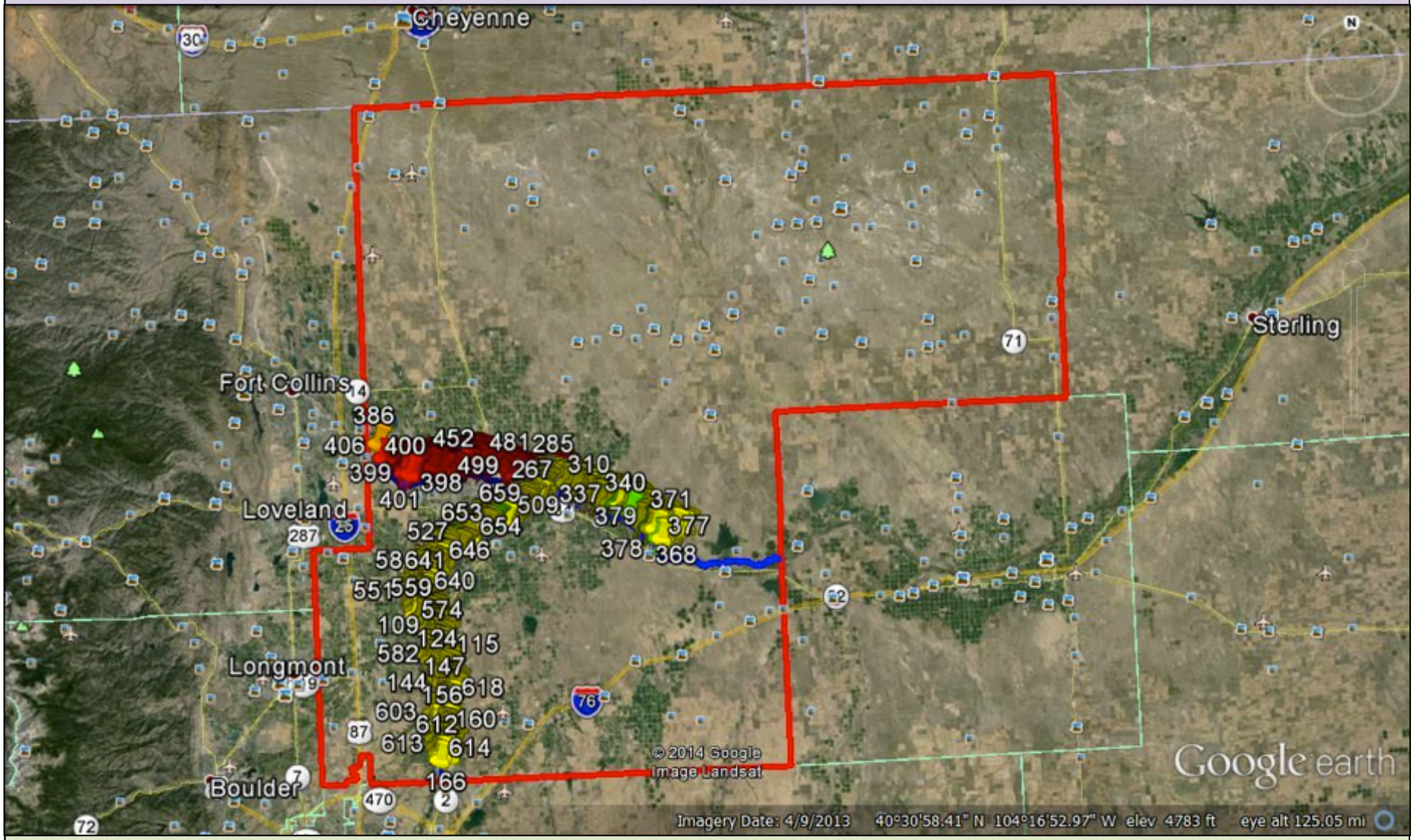
The new gas-fired facility is comprised of two combustion turbines, two heat recovery steam generators and a steam turbine.

Original coal fired Units 1, 2 and 3 have been retired. Unit 4 will be converted from coal to natural gas by the end of 2017.

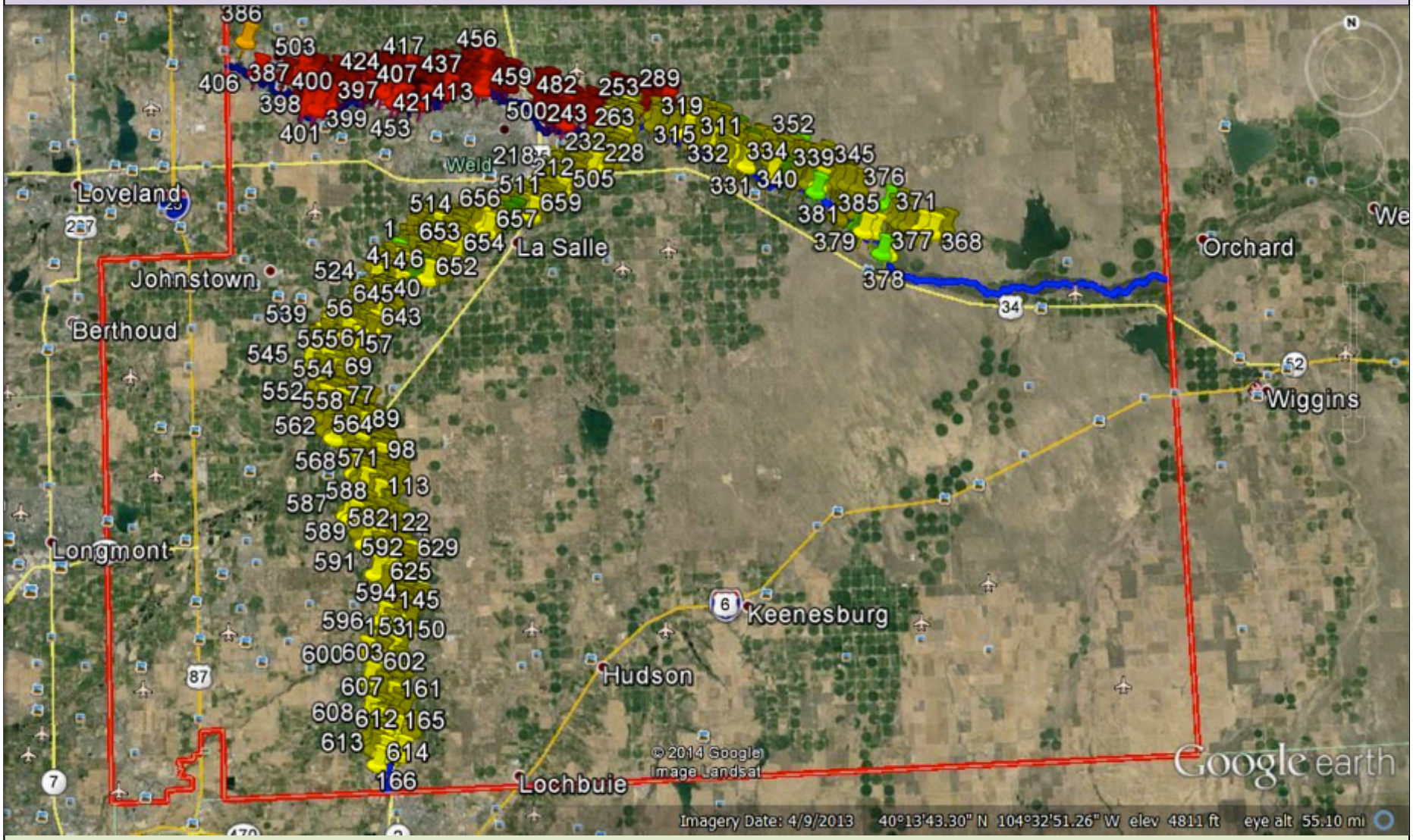
Cherokee's new gas-fired units operate much cleaner than the original coal-fired units.



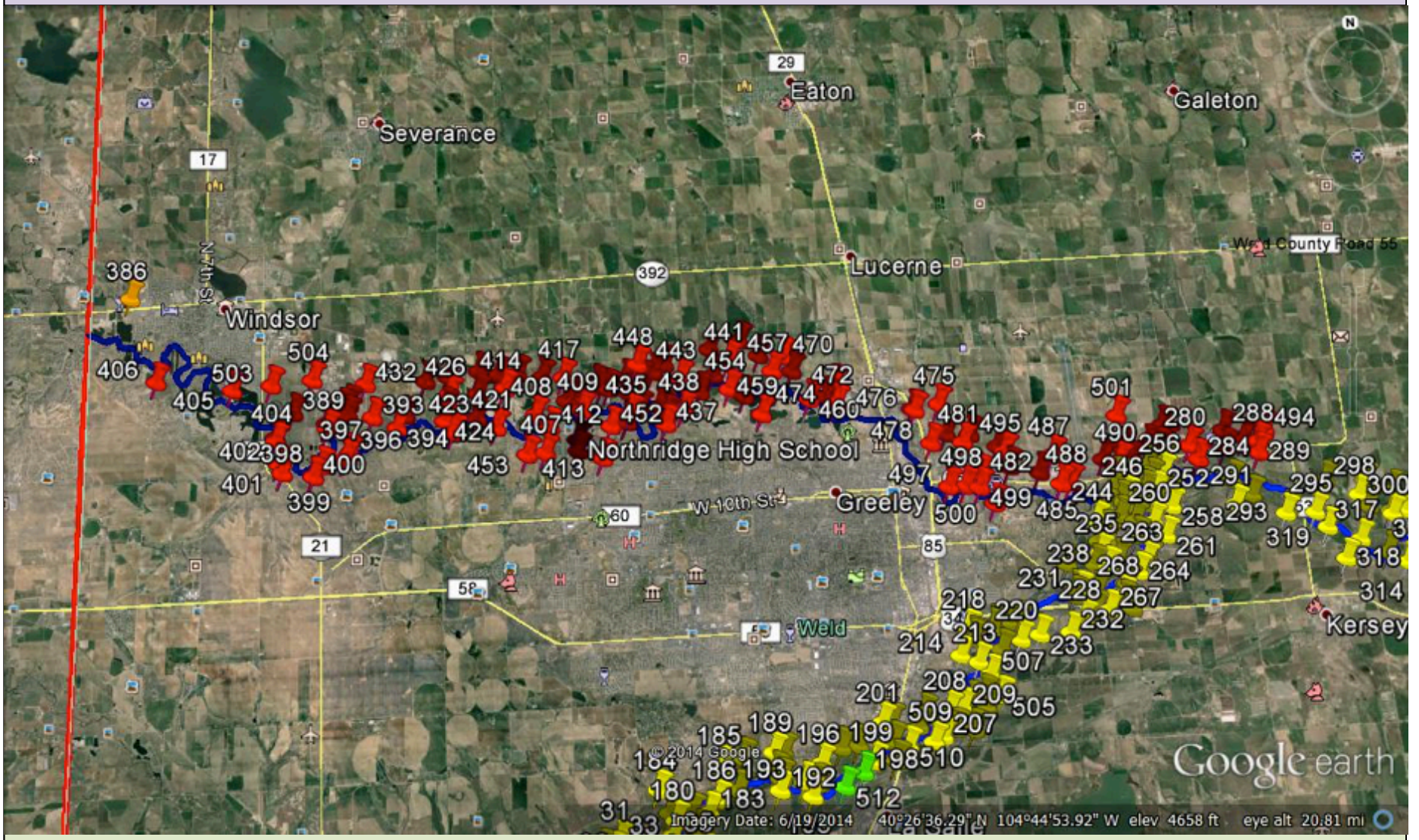
Natural Gas Wells in Weld County, CO



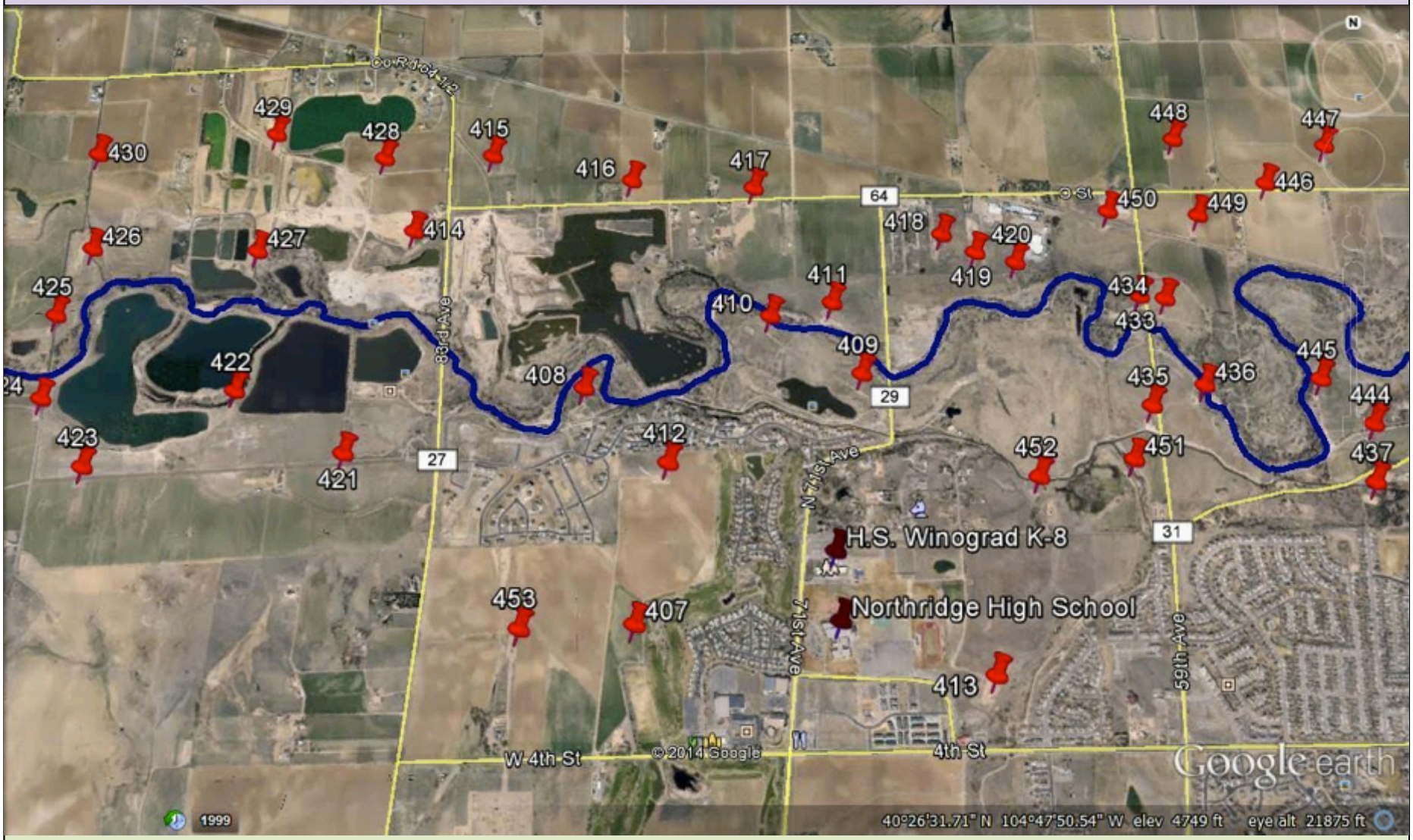
Natural Gas Wells in Weld County, CO



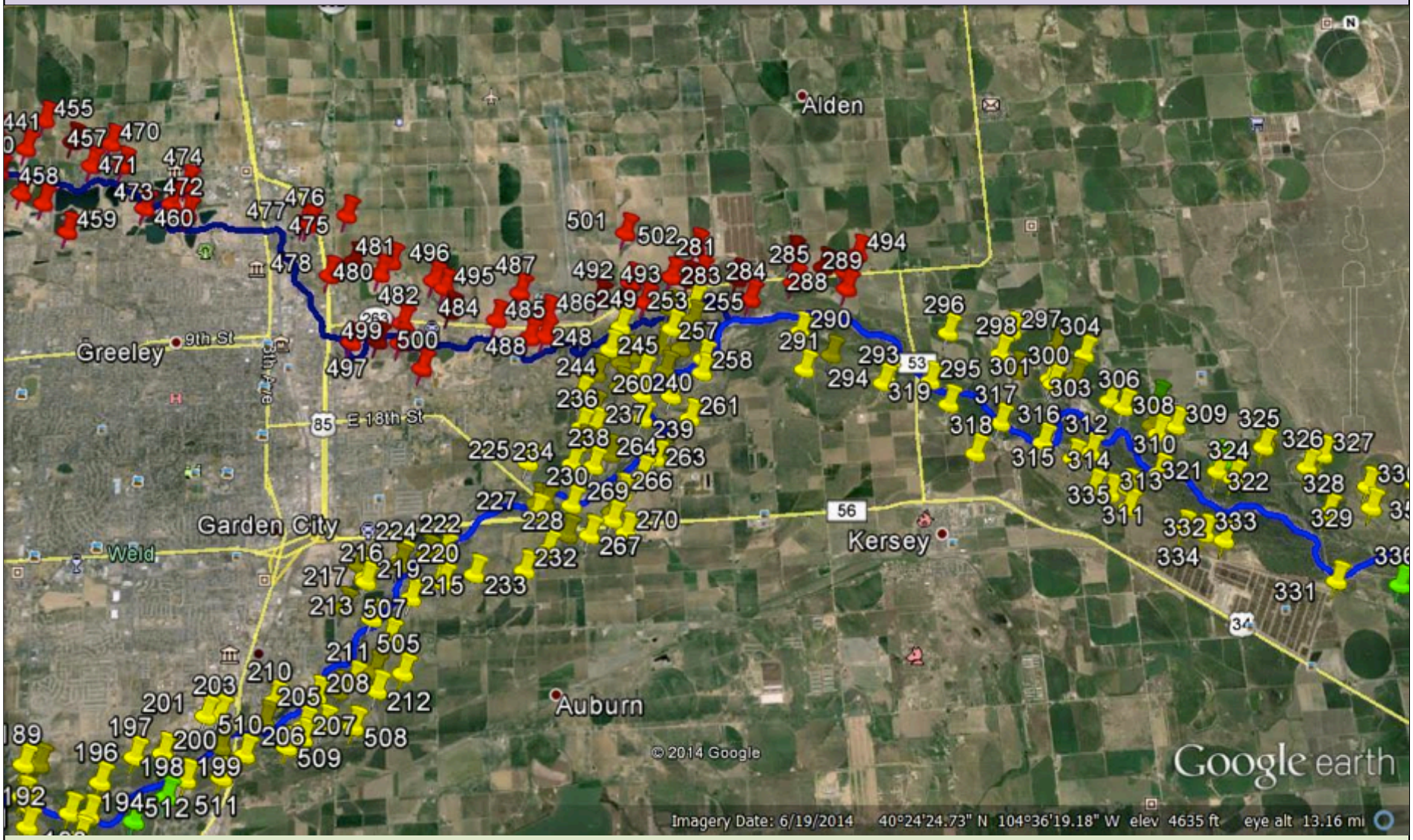
Natural Gas Wells in Weld County, CO



Natural Gas Wells in Weld County, CO



Natural Gas Wells in Weld County, CO

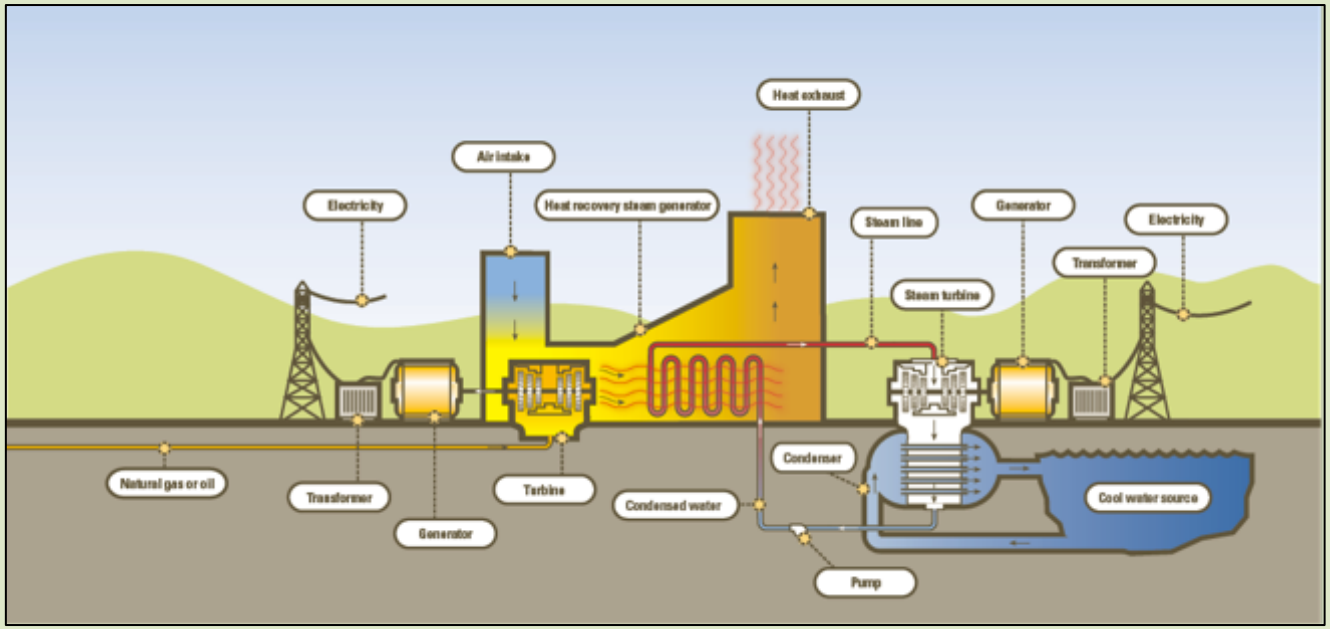


Natural Gas

According to the Energy Information Administration (EIA), U.S. carbon dioxide emissions have been reduced by 12.2% since they peaked in 2007.

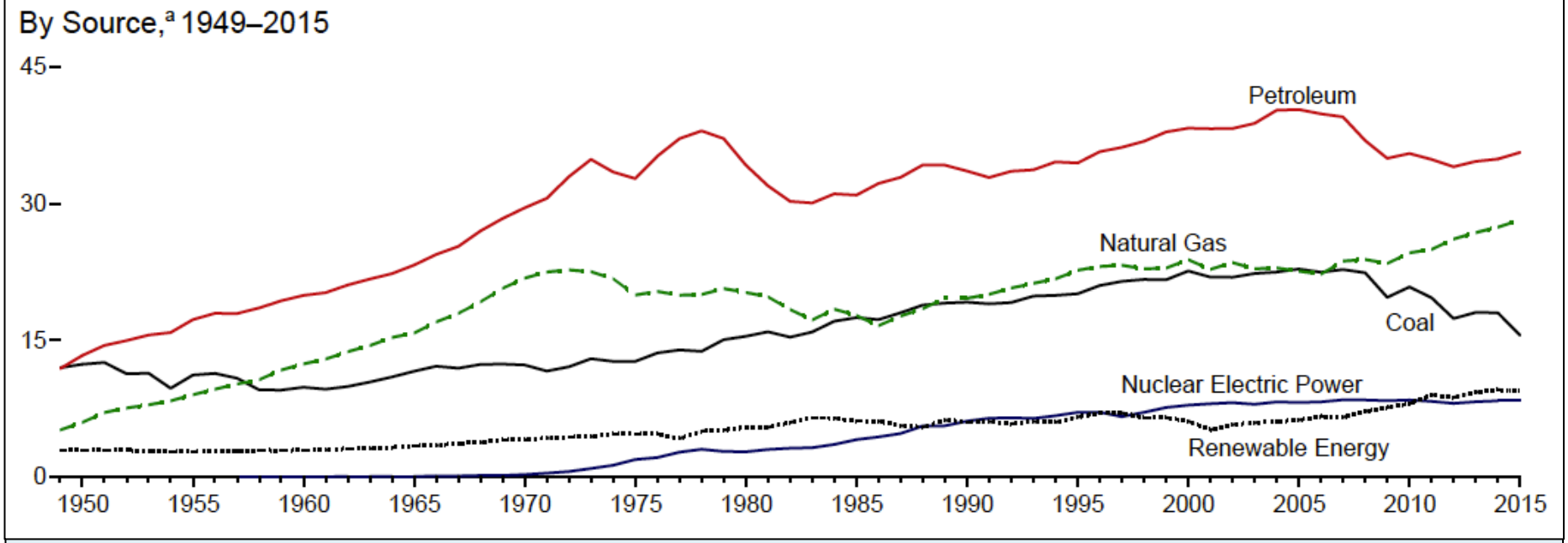
According to the Washington Times, the United States has reduced it's carbon dioxide emissions more than virtually any other nation in the world.

This is largely due to the development of hydraulic fracturing, and its use in producing natural gas from shale; coupled with the conversion of coal-fired power plants to cleaner burning natural gas.



Natural Gas

Patterns of Energy Use in US- By Fuel Source



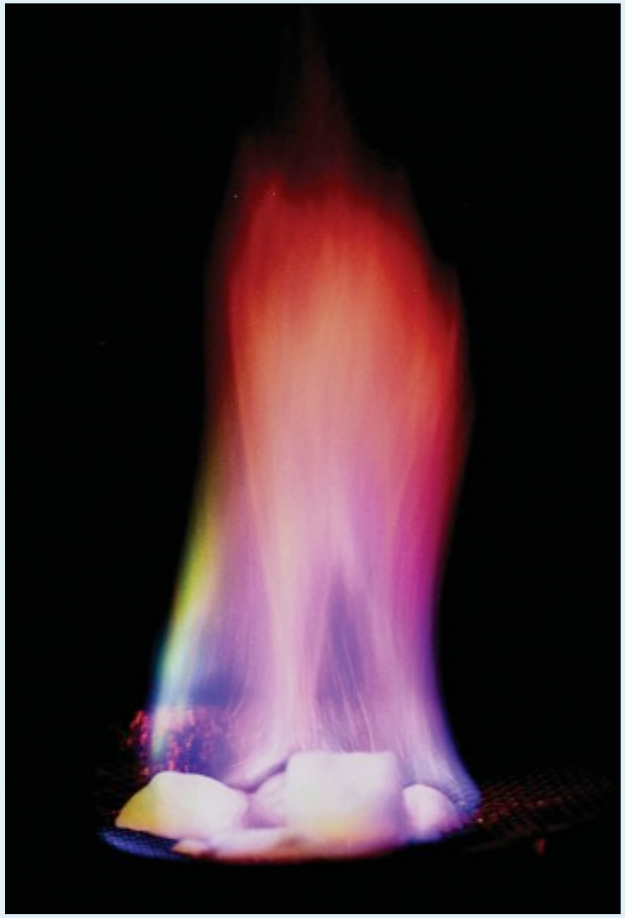
Other Unconventional Natural Gas Sources

Coal bed methane gas

- In coal beds near the earth's surface
- Extraction results in high environmental impacts

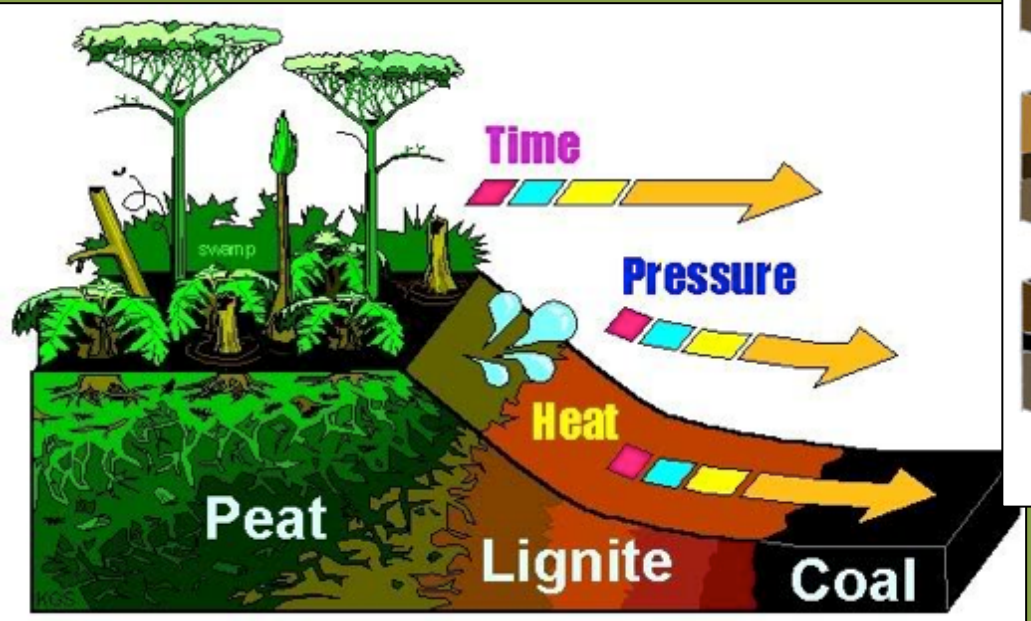
Methane hydrate

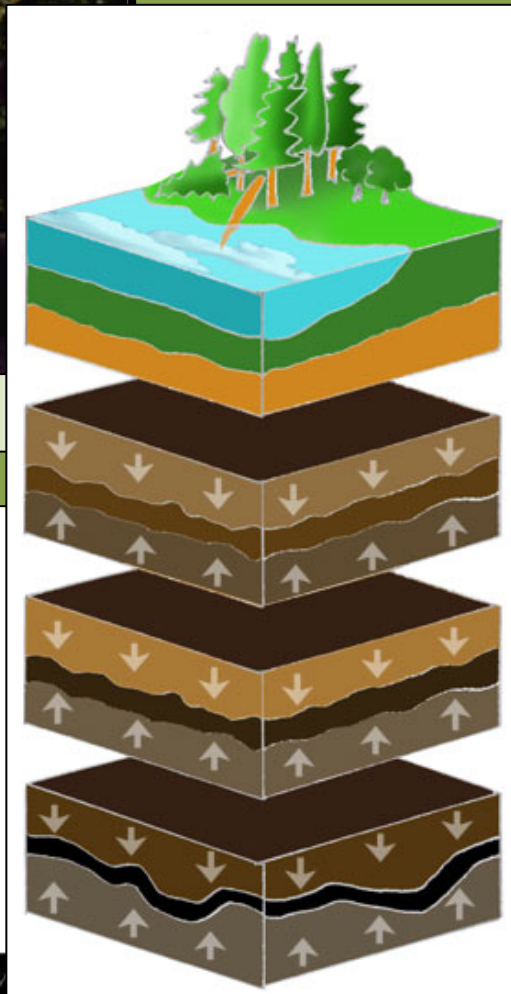
- Trapped in icy water
- In permafrost environments
- On ocean floor
- Costs of extraction currently too high



Coal

Model of a Pennsylvanian Coal Swamp





HUGE FORESTS GREW AROUND 300 MILLION YEARS AGO COVERING MOST OF THE EARTH

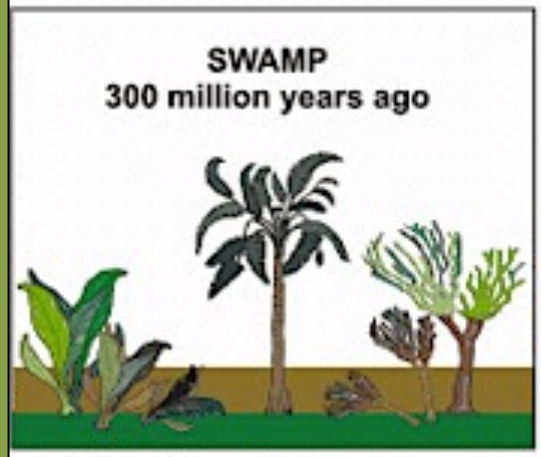
THE VEGETATION DIES AND FORMS PEAT

THE PEAT IS COMPRESED BETWEEN SEDIMENT LAYERS TO FORM LIGNITE

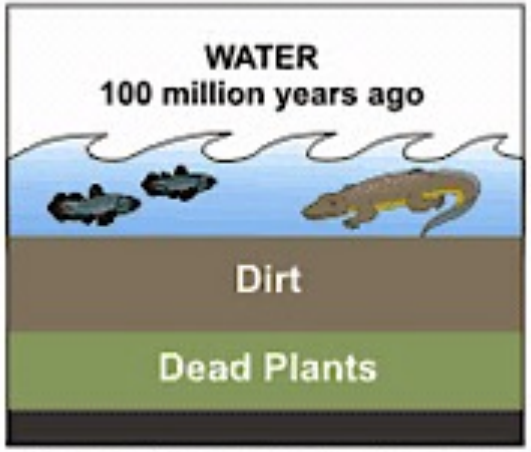
FURTHER COMPRESSION FORMS BITUMINOUS AND SUBITTUMINOUS COAL

EVENTUALLY ANTHRACITE FORMS

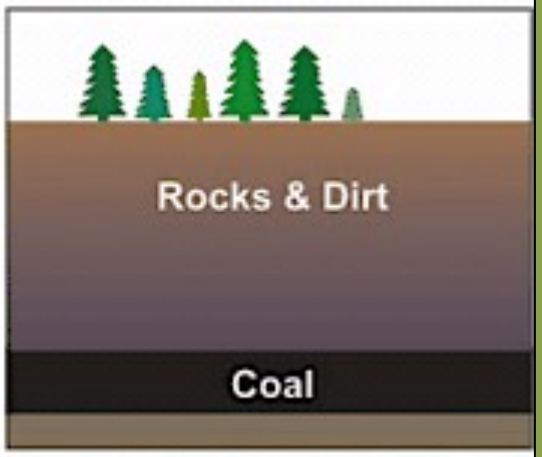
HOW COAL WAS FORMED



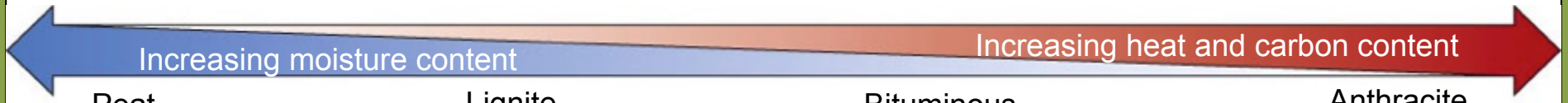
Before the dinosaurs, many giant plants died in swamps.



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



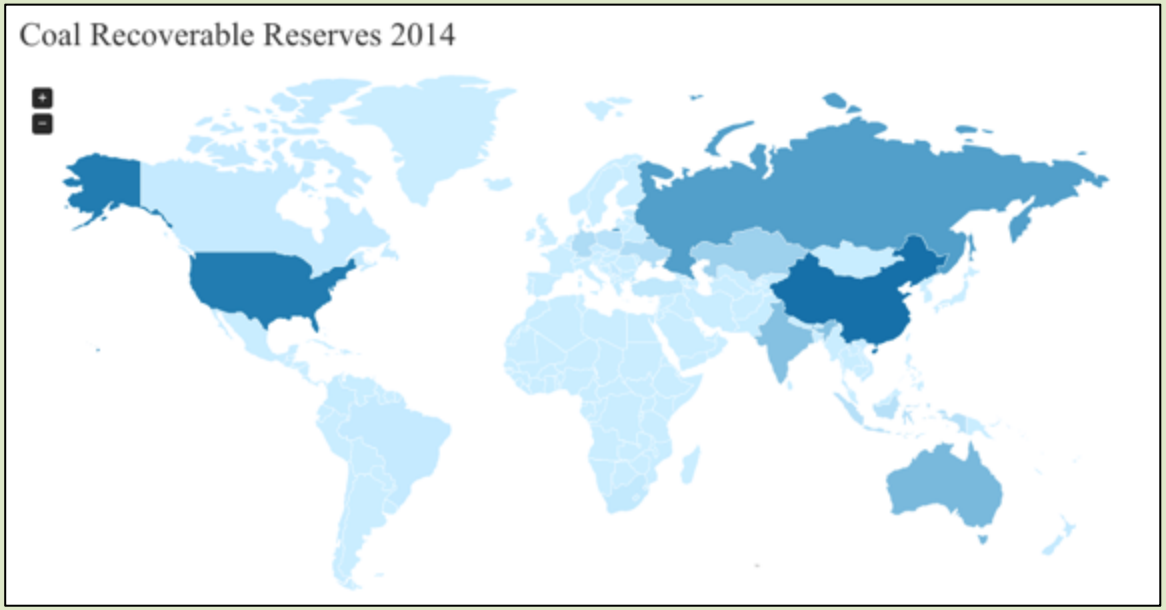
Heat and pressure turned the dead plants into coal.

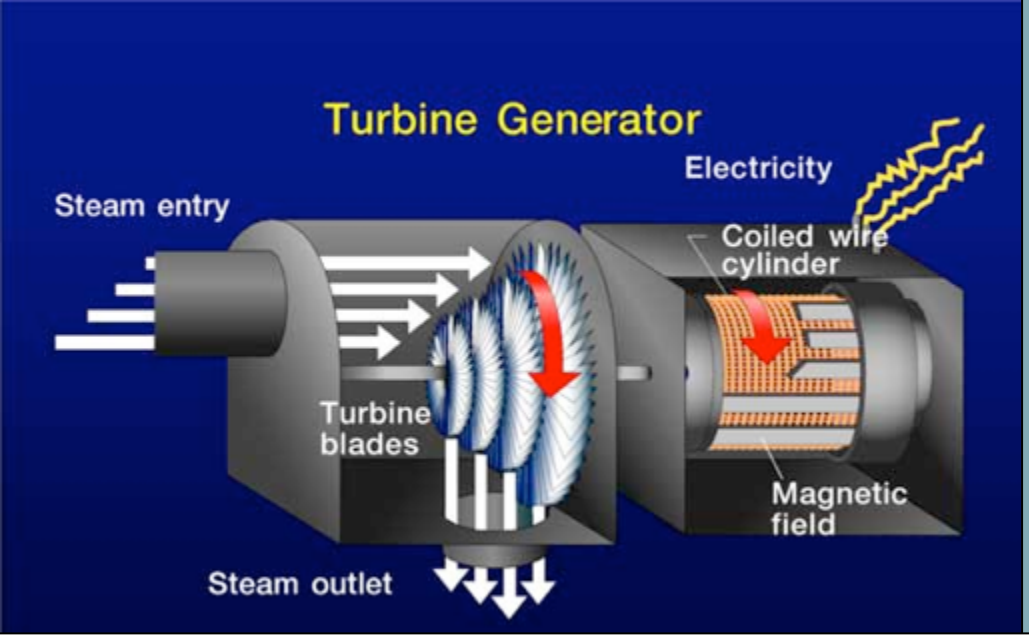


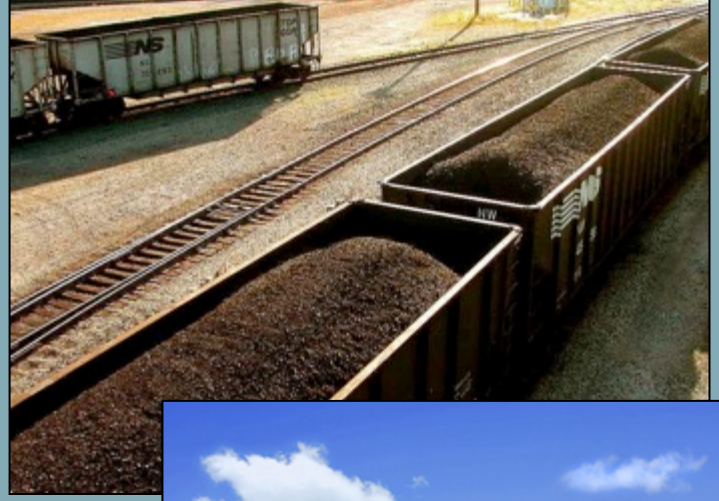
Peat (not a coal)	Heat / Pressure	Lignite (brown coal)	Heat / Pressure	Bituminous (soft coal)	Heat / Pressure	Anthracite (hard coal)
						
Partially decayed plant matter in swamps and bogs; low heat content		Low heat content; low sulfur content; limited supplies in most areas		Extensively used as a fuel because of its high heat content and large supplies; normally has a high sulfur content		Highly desirable fuel because of its high heat content and low sulfur content; supplies are limited in most areas

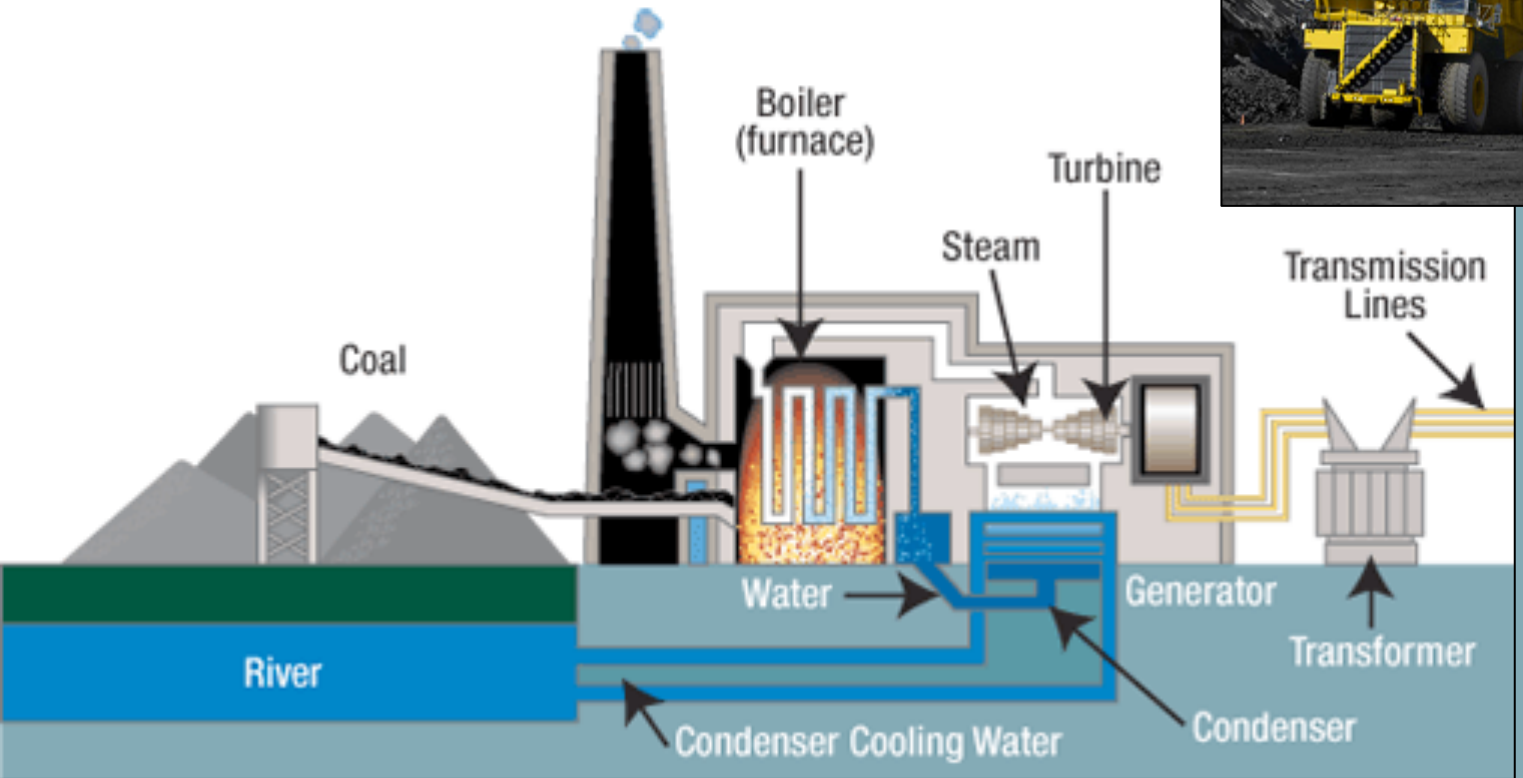
Coal Is a Plentiful but Dirty Fuel

- Coal is a solid fossil fuel (mostly carbon). It is burned in power plants and is the single largest source fuel used to produce electricity; also important in steel production.
- Coal is the world's most abundant fossil fuel. The U.S. has 28% of proven reserves (could last 300 years); followed by Russia (18%); China, which ranks third (13%), is the biggest producer and consumer of coal.
- The three largest coal-burning countries: China, United States, India

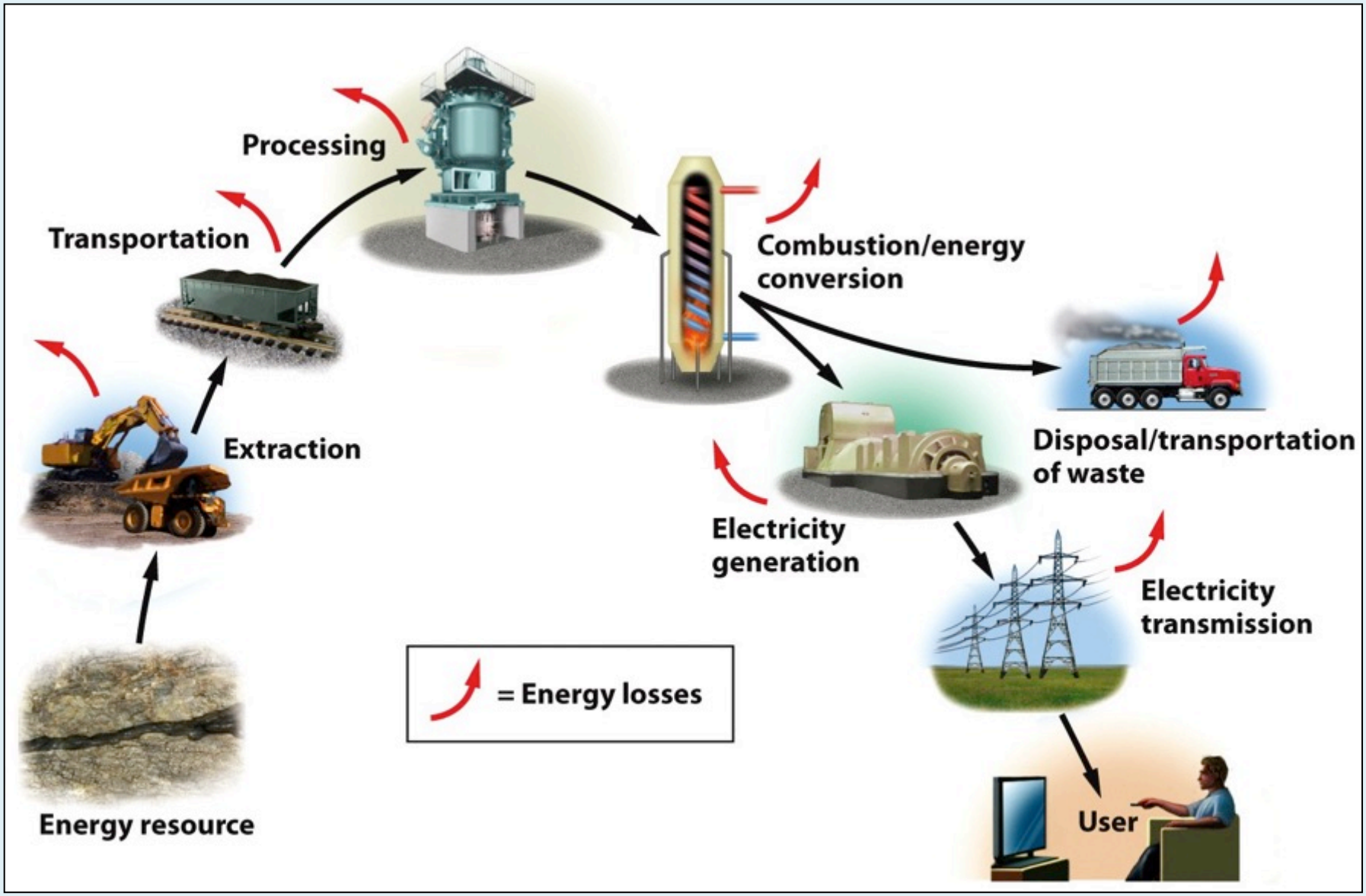



Turbine Generator
Electricity
Steam entry
Coiled wire cylinder
Turbine blades
Magnetic field
Steam outlet




Boiler (furnace)
Turbine
Steam
Transmission Lines
Coal
Water
Generator
Transformer
River
Condenser Cooling Water
Condenser

Coal Supply Chain & Energy Losses



Coal Is a Plentiful but Dirty Fuel

Environmental Costs of Burning Coal

Severe air pollution

- Sulfur released as sulfur dioxide (SO_2)
- Nitrogen oxides released (NO_x)
- Large amount of soot
- Greenhouse gas: carbon dioxide (CO_2); 35% of all global CO_2 releases are due to burning coal.
- Emits toxins such as: mercury ,arsenic, lead, cadmium, and trace amounts of radioactive uranium & thorium

Mining results in habitat loss, water and air pollution.

Coal Is a Plentiful but Dirty Fuel

The Problem of Coal Ash

Ash left from burning and from emissions is highly toxic; contains:

- Arsenic, cadmium, chromium, lead, mercury

- Most is buried or stored in containment ponds; can contaminate groundwater & should be classified as hazardous waste

The Clean Coal Campaigns

Coal companies and energy companies fought:

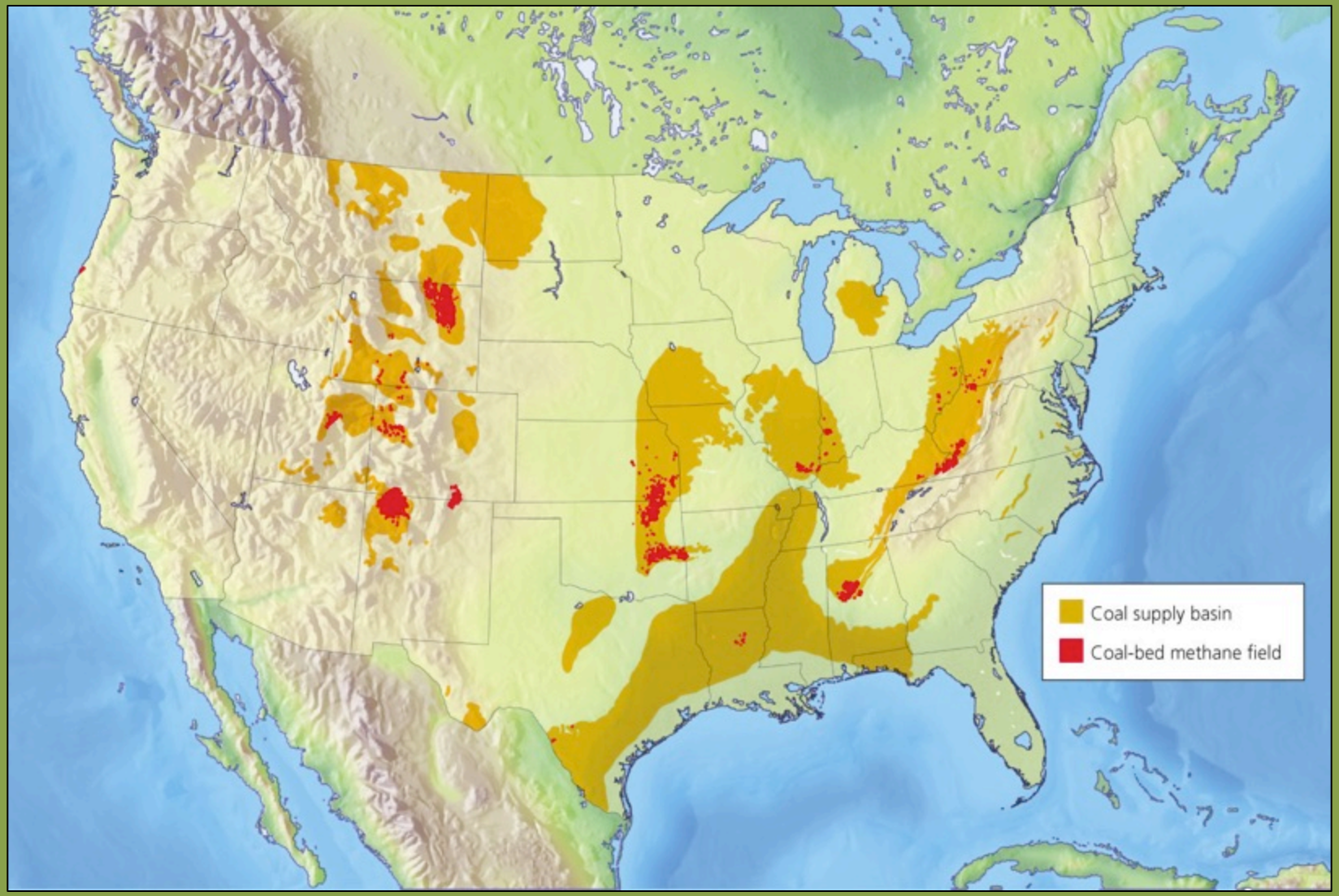
- Classifying carbon dioxide as a pollutant
- Classifying coal ash as hazardous waste
- Air pollution standards for emissions

2008 clean coal campaign was political scheme based on undeveloped technologies of carbon capture and sequestration (power plants capture CO_2 , store it or use it for other industrial purposes; but no such thing as clean coal

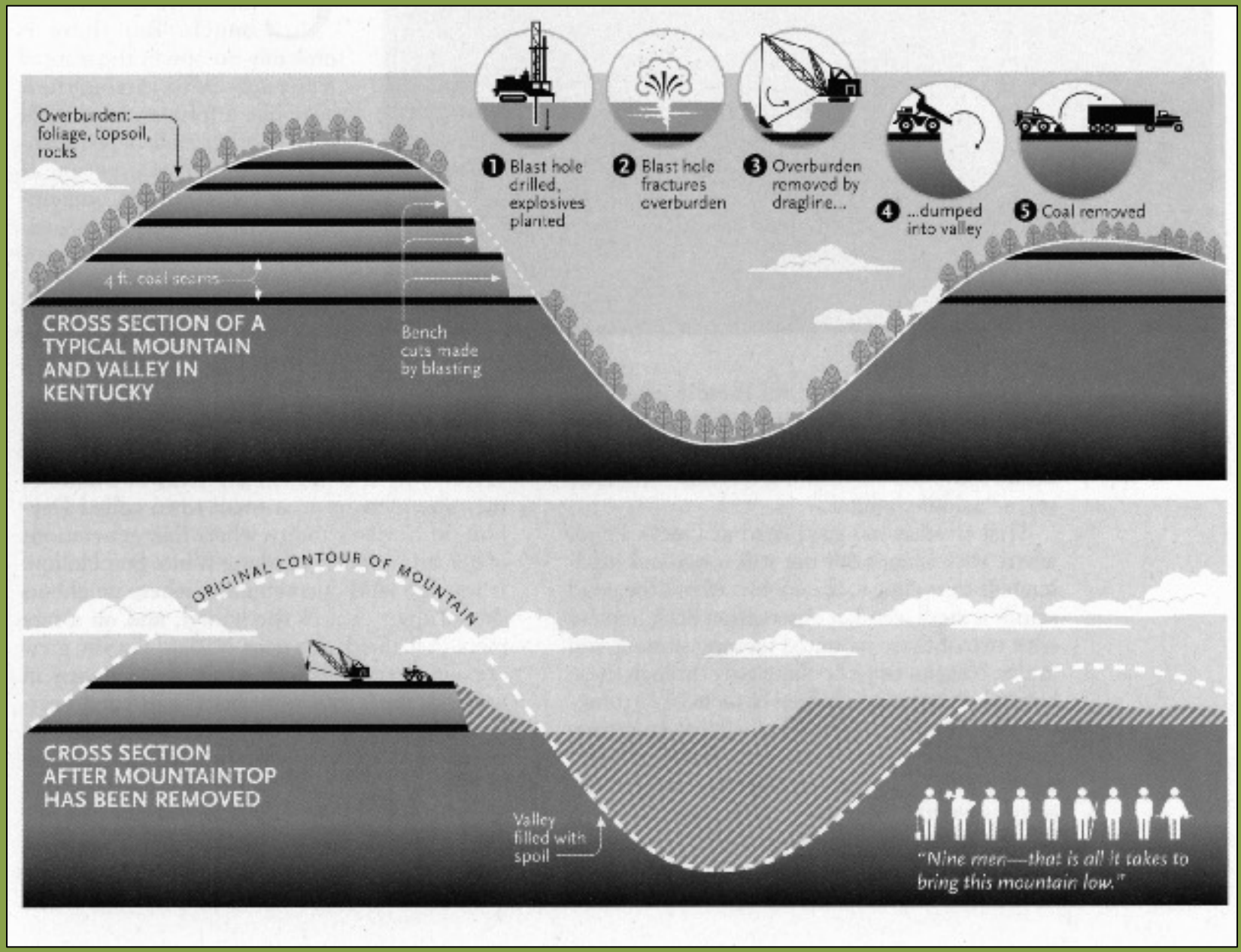
"Coal is the single greatest threat to civilization and all life on the planet."

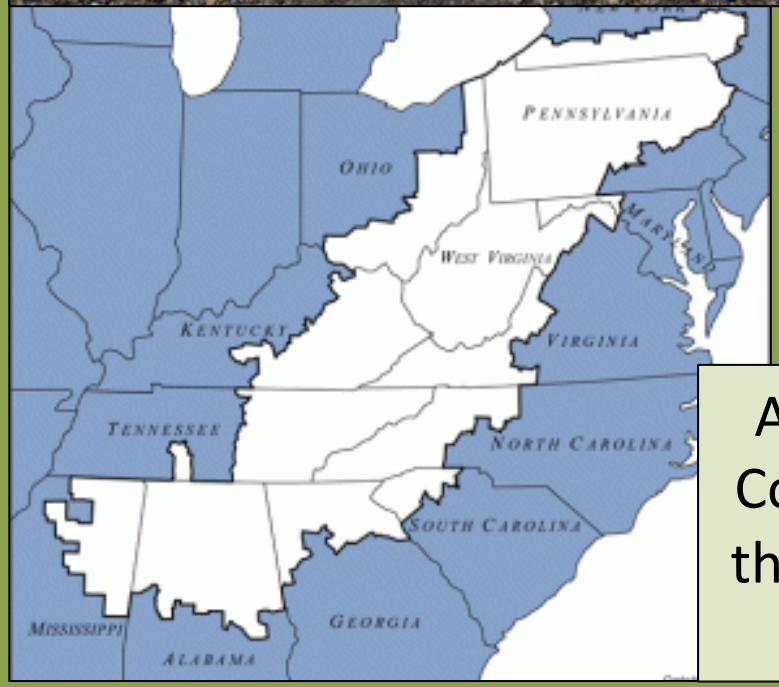
– James Hansen

Coal Deposits in the United States



Mountaintop Removal Coal Mining



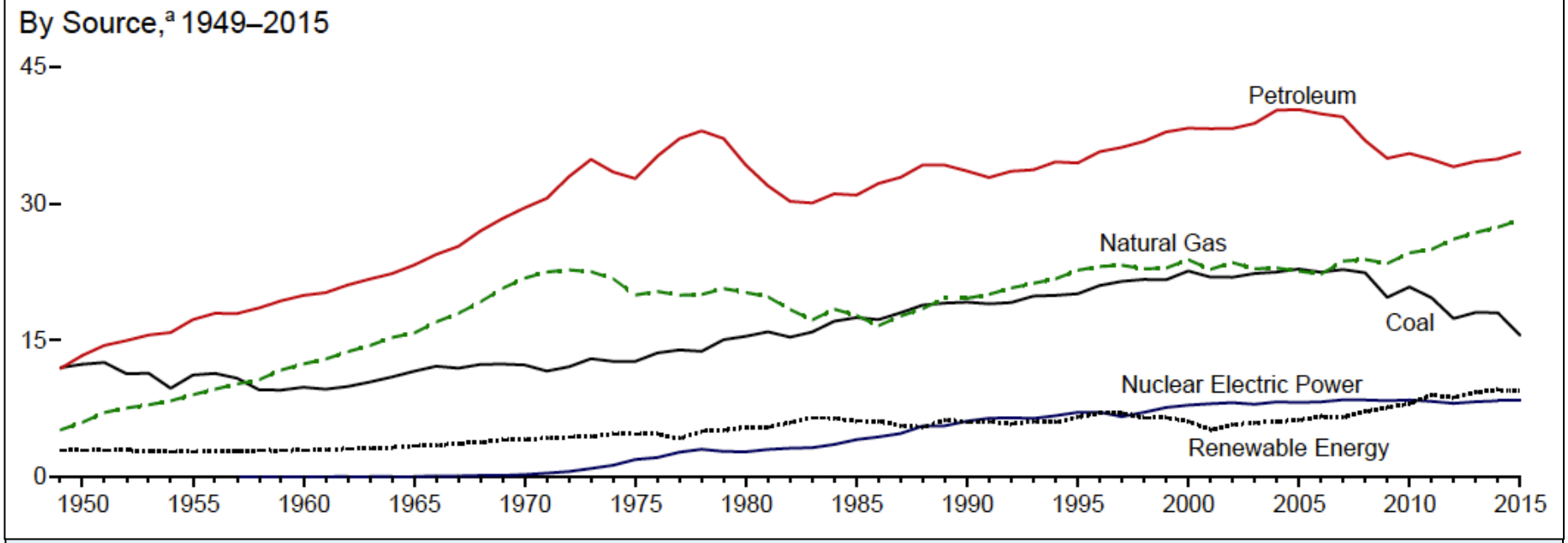


A coal sludge dam breach in Marin County, Kentucky (2000); Sent more than 300 million gallons of toxic coal sludge into the valley.

Marsh Fork Elementary in Sundial, West Virginia- precariously set about 400 feet downhill from a massive 2.8-billion-gallon pool of toxic coal sludge.

Coal Is a Plentiful but Dirty Fuel

Patterns of Energy Use in US- By Fuel Source



Summary: Conventional coal is plentiful and has a high net energy yield and low cost, but it has a very high environmental impact.

Trade-Offs

Coal

Advantages

Ample supplies in many countries

Easy to make electricity

High net energy yield

Low cost when environmental costs are not included

Disadvantages

Mining: Severe land disturbance and water pollution

Fine particle and toxic mercury emissions threaten human health

Sulfur emissions = acid rain

Emits large amounts of CO_2 and other air pollutants when produced and burned; 60% more carbon released compared to oil and gas.