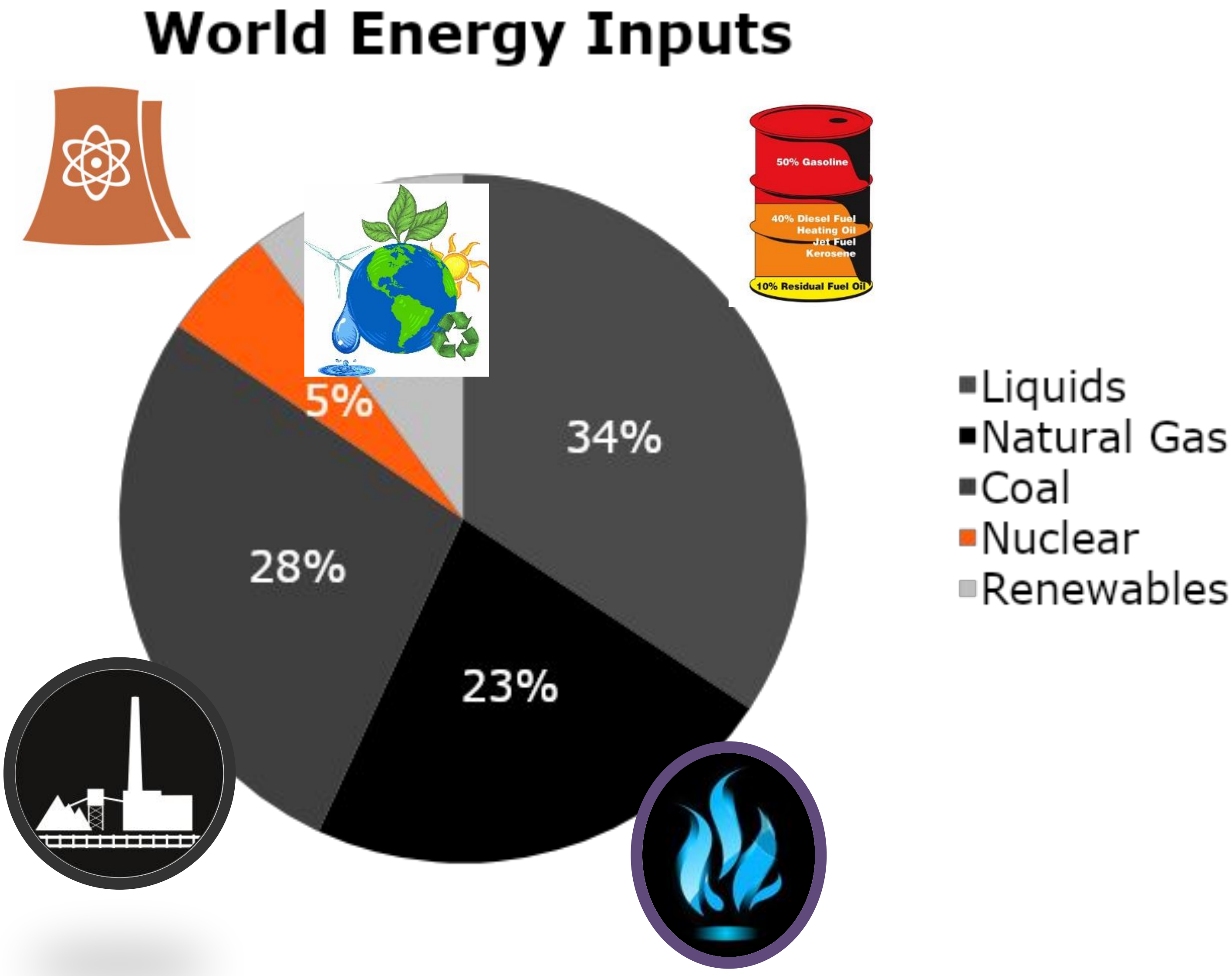
IE350
Alternative Energy Course

Lecture #3
Energy Resources: Carbon Cycle

Your homework

- -3 use a more appropriate number format, e.g. 1,000,000 = mln.
- Please provide the answer: how many more time energy will be needed?
- -5 use proper units
- - 10 Do not induce any anachronism – all numbers should be for the same year.

2008 Energy Use = 505 Quads



World Energy Inputs

Oil and Gas Liquids

Oil and Gas Liquids

Blessings

- Mostly used to for transportation, cars, trucks, aircraft, rail, etc.
- Also used to make petrochemicals, asphalt, lubricants, electricity, etc.
- Enables international trade
- Is closely tied to world economies
- Very easy to transport to refine and as final product
- Burning has low acute hazards
- Easily stored at distribution points
- Exceedingly high energy density
  - 1 barrel = $84,000 of manual labor
  - allows for long range transport
  - only fuel that enables air travel
- Has established an infrastructure for other liquid fuels

Curses

- Oil drilling & refining is hazardous
  - to workers, fire, explosion, etc.
  - spills into the environment
- Transporting oil is not without risk
  - pollution
  - theft and terrorism
- Burning oil is not clean
  - pollution
  - greenhouse gas (CO_2) emissions
- Large reserves are in politically unstable countries
- Human rights violations track with high oil prices
- Easy half of oil has been pumped
- Future oil will be more difficult to extract ∴ more expensive
- Price instability

Oil and Gas Liquids

Curses

Coal

Coal

Blessings

- Mostly used to make electricity
- Abundant domestically & world-wide (US has the most)
- Abundance = affordable
- Available from politically stable countries
- Relatively easy to transport
- Burning has low acute hazards
- Easily stored at power plant
- Operation independent of
  - weather dependent
  - seasons
  - time of day
- Can be converted into a liquid fuel

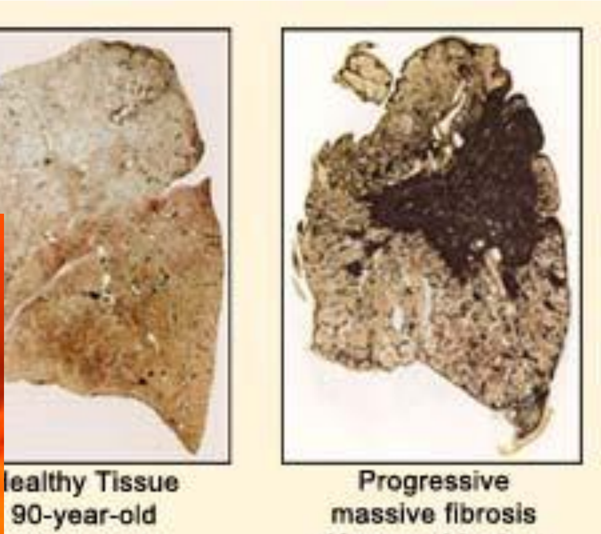
Curses

- Coal mining is very dangerous
  - fires and explosions
  - black lung
- Transportation can be hazardous
- Burning coal is not clean
  - high chronic hazards
  - pollution (gases, heavy metals, radioactivity, etc.)
  - greenhouse gas (CO_2) emissions
  - sequestered products still hazardous
- Centralized electric power generation
  - security risk
  - copious quantities of cooling water
  - most energy is lost to heat (>60%)
- Environmental impacts
  - mining
  - emissions
  - tailings
- Liquefaction losses of >50% before internal combustion losses of > 75%

Coal

Curses


UF IX
UF IX


lealthy Tissue
90-year-old
chooIteacher
Progressive
massive fibrosis
40-year-old-miner

Natural Gas

Natural Gas

Blessings

- Very diverse fuel source
  - space and water heating
  - electricity generation
  - chemical production (e.g., fertilizer)
  - industrial manufacturing
  - cooking and clothes drying
  - dehumidifying and incineration
- Can be piped directly to buildings for multiple uses
- Somewhat easy to transport
- Available from many countries, including politically stabile ones
- Burning has low acute hazards
- Can be stored for future use
- For electricity generation vs. coal
  - spins up turbines faster
  - burns cleaner
  - smaller plant footprint (no trains)

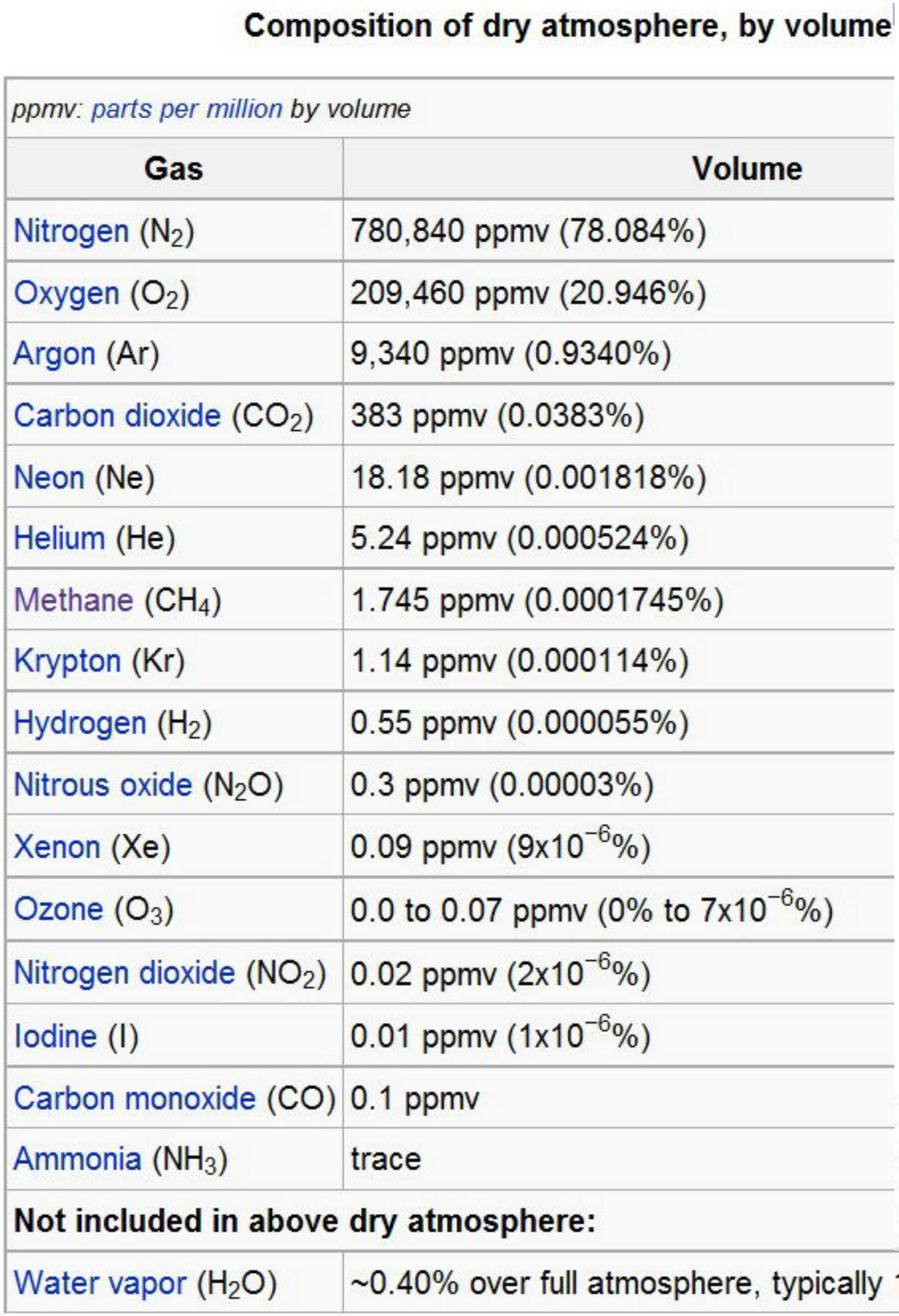
Curses

- Gas drilling is hazardous
  - to workers, fire, explosion, etc.
  - pumping fluids reaching groundwater
  - leaks from fractured bed rock
  - number of wells rapidly increasing
- Transportation can be hazardous
  - pipeline explosions (old infrastructure)
  - liquefied natural gas is highly volatile
- Greenhouse gas issues
  - burning produces CO_2 emissions
  - leaked CH_4 traps 72x the heat of CO_2
- Centralized electric power generation
  - security risk
  - copious quantities of cooling water
  - most energy is lost to heat (>60%)
- Not a good transportation fuel
  - not a liquid ∴ different infrastructure
  - resource size doesn’t match the transportation sector’s size/demand
  - energy density is lower than gasoline

Natural Gas

Curses

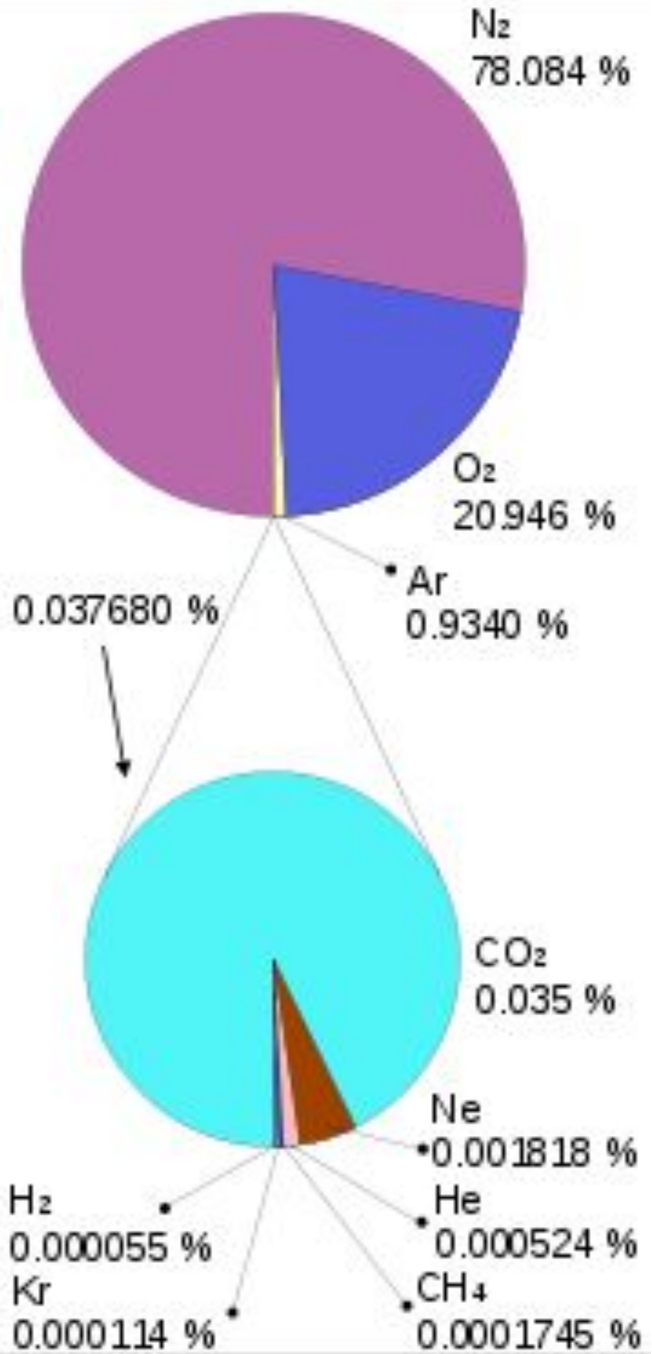
Earth atmosphere composition



Composition of dry atmosphere, by volume

ppmv: parts per million by volume

Gas	Volume
Nitrogen (N_2)	780,840 ppmv (78.084%)
Oxygen (O_2)	209,460 ppmv (20.946%)
Argon (Ar)	9,340 ppmv (0.9340%)
Carbon dioxide (CO_2)	383 ppmv (0.0383%)
Neon (Ne)	18.18 ppmv (0.001818%)
Helium (He)	5.24 ppmv (0.000524%)
Methane (CH_4)	1.745 ppmv (0.0001745%)
Krypton (Kr)	1.14 ppmv (0.000114%)
Hydrogen (H_2)	0.55 ppmv (0.000055%)
Nitrous oxide (N_2O)	0.3 ppmv (0.00003%)
Xenon (Xe)	0.09 ppmv (9×10^{-6}%)
Ozone (O_3)	0.0 to 0.07 ppmv (0% to 7×10^{-6}%)
Nitrogen dioxide (NO_2)	0.02 ppmv (2×10^{-6}%)
Iodine (I)	0.01 ppmv (1×10^{-6}%)
Carbon monoxide (CO)	0.1 ppmv
Ammonia (NH_3)	trace
Not included in above dry atmosphere:	
Water vapor (H_2O)	~0.40% over full atmosphere, typically 1%-4% at surface

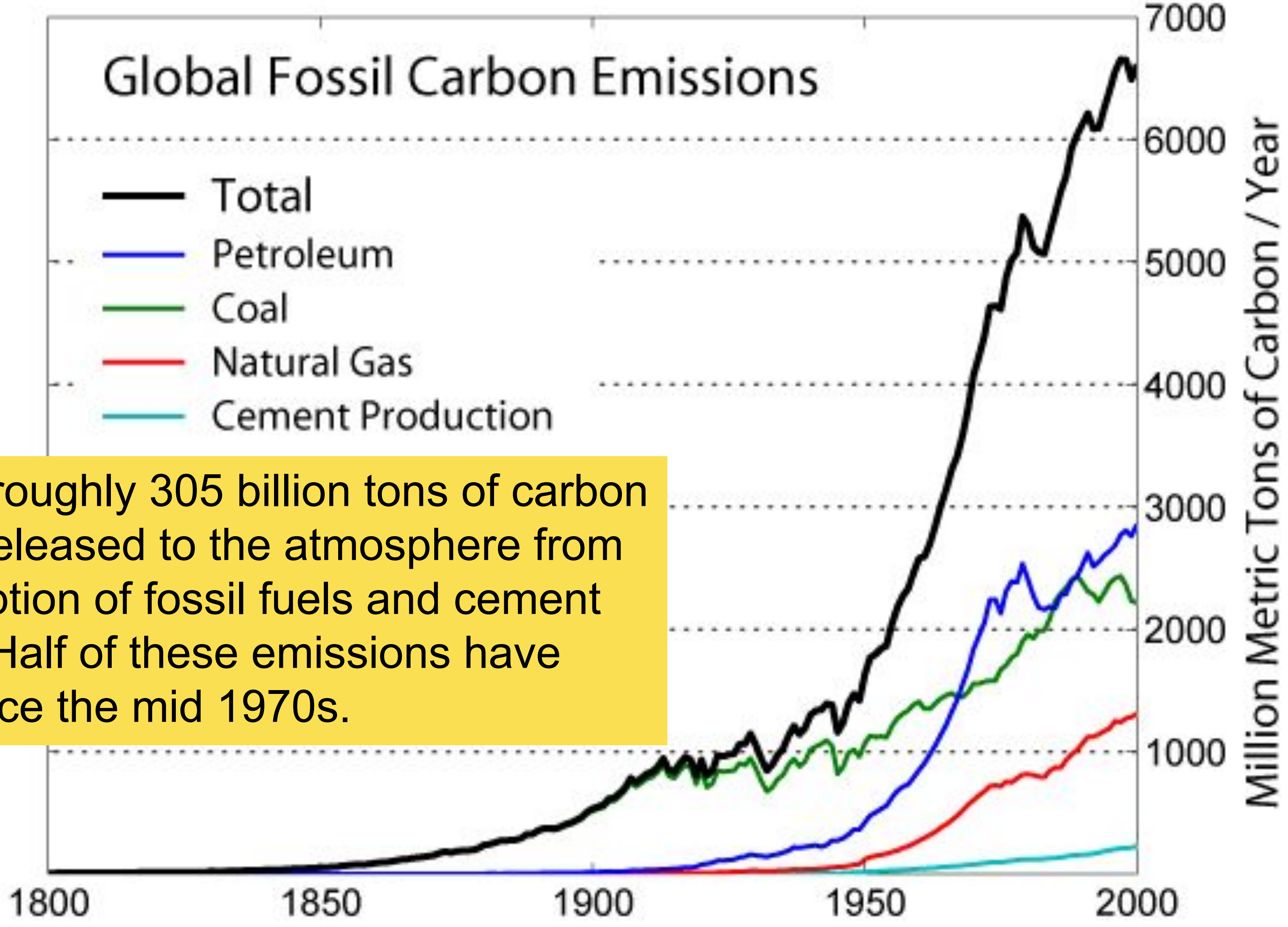


Global Warming Potential - GWP

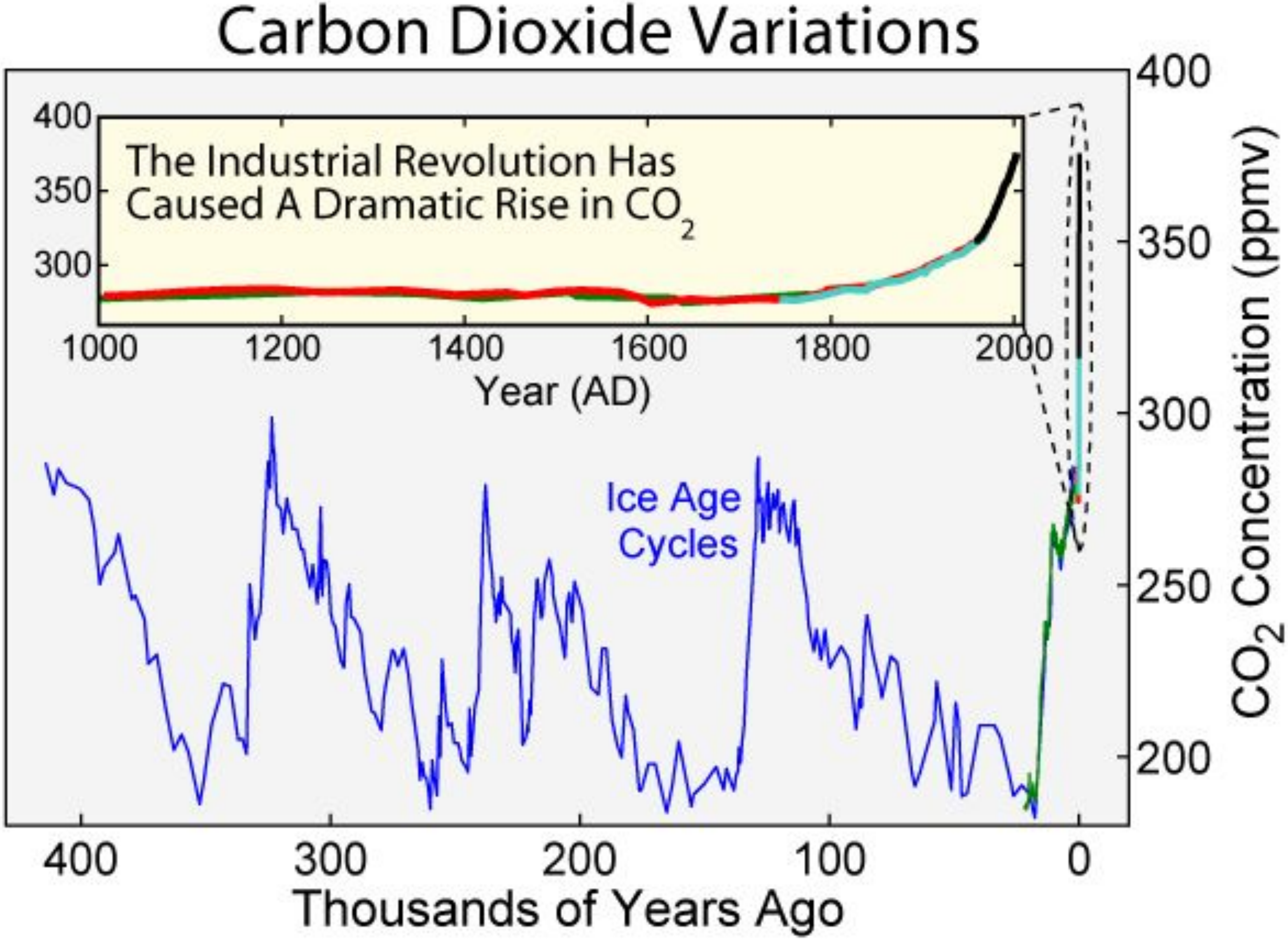
Carbon dioxide has a GWP of exactly 1.
It is the baseline unit to which all other greenhouse gases are compared

GWP values and lifetimes from 2007 IPCC AR4 p212	**Lifetime (years)**	**GWP time horizon**		
(2001 IPCC TAR in parentheses)		**20 years**	**100 years**	**500 years**
Methane	12 (12)	72 (62)	25 (23)	7.6 (7)
Nitrous oxide	114 (114)	289 (275)	298 (296)	153 (156)
HFC-23 (hydrofluorocarbon)	270 (260)	12,000 (9400)	14,800 (12,000)	12,200 (10,000)
HFC-134a (hydrofluorocarbon)	14 (13.8)	3,830 (3,300)	1,430 (1,300)	435 (400)
Sulfur hexafluoride	3200 (3,200)	16,300 (15,100)	22,800 (22,200)	32,600 (32,400)

History of CO_2 Emissions

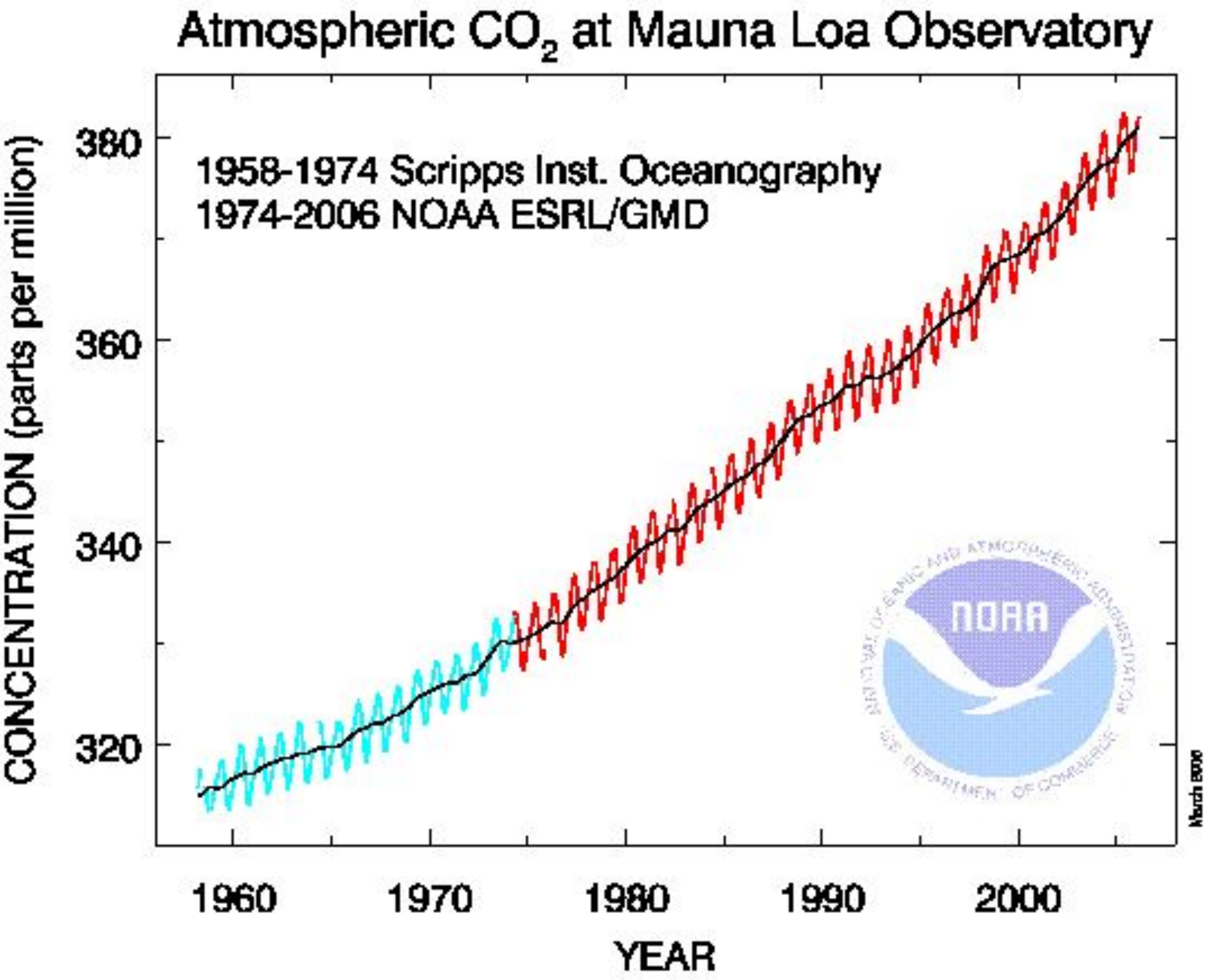


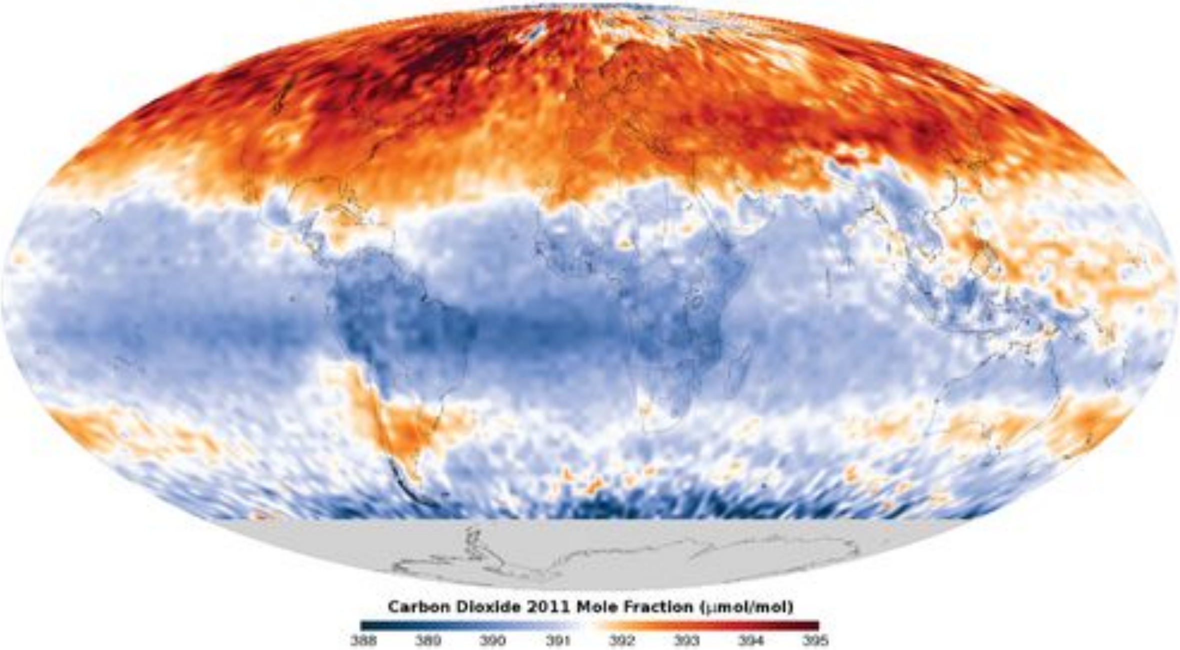
Since 1751 roughly 305 billion tons of carbon have been released to the atmosphere from the consumption of fossil fuels and cement production. Half of these emissions have occurred since the mid 1970s.


Carbon Dioxide Variations
The Industrial Revolution Has Caused A Dramatic Rise in CO_2
400
350
300
1000
1200
1400
1600
1800
2000
Year (AD)
Ice Age Cycles
400
350
300
250
200
CO_2 Concentration (ppmv)
400
300
200
100
0
Thousands of Years Ago

Actual CO_2 Concentration

0.038%





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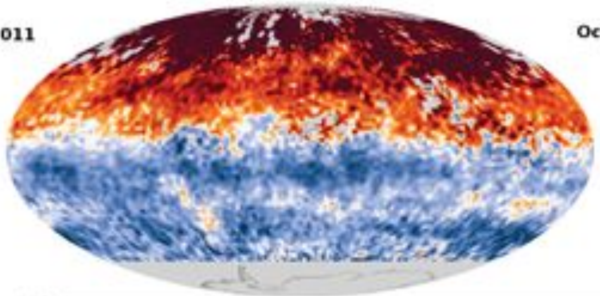

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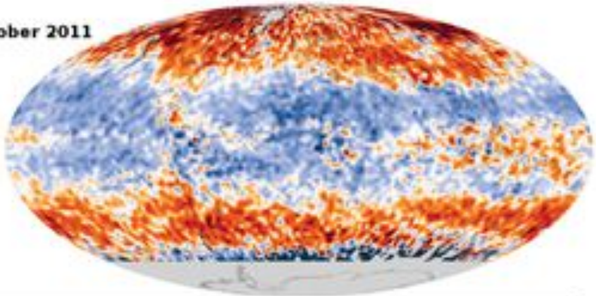
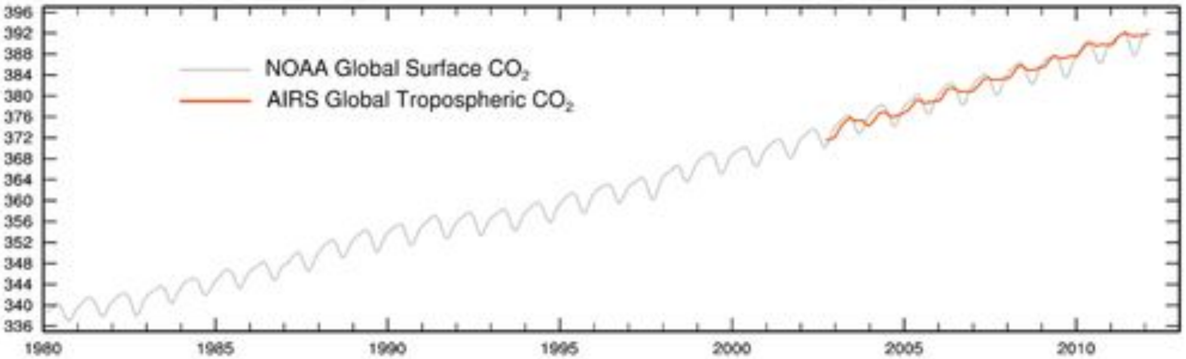
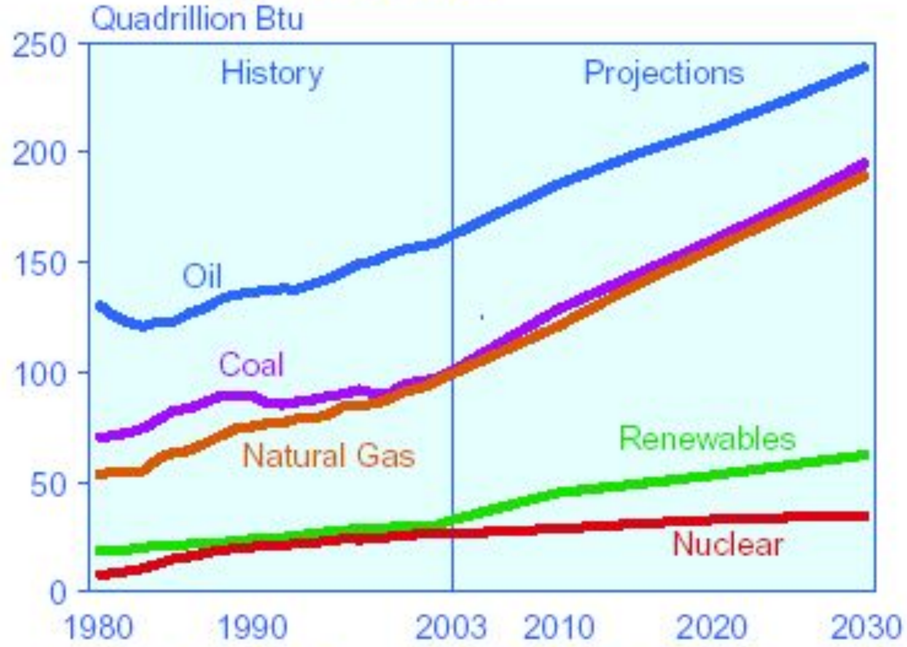




The history of human energy consumption

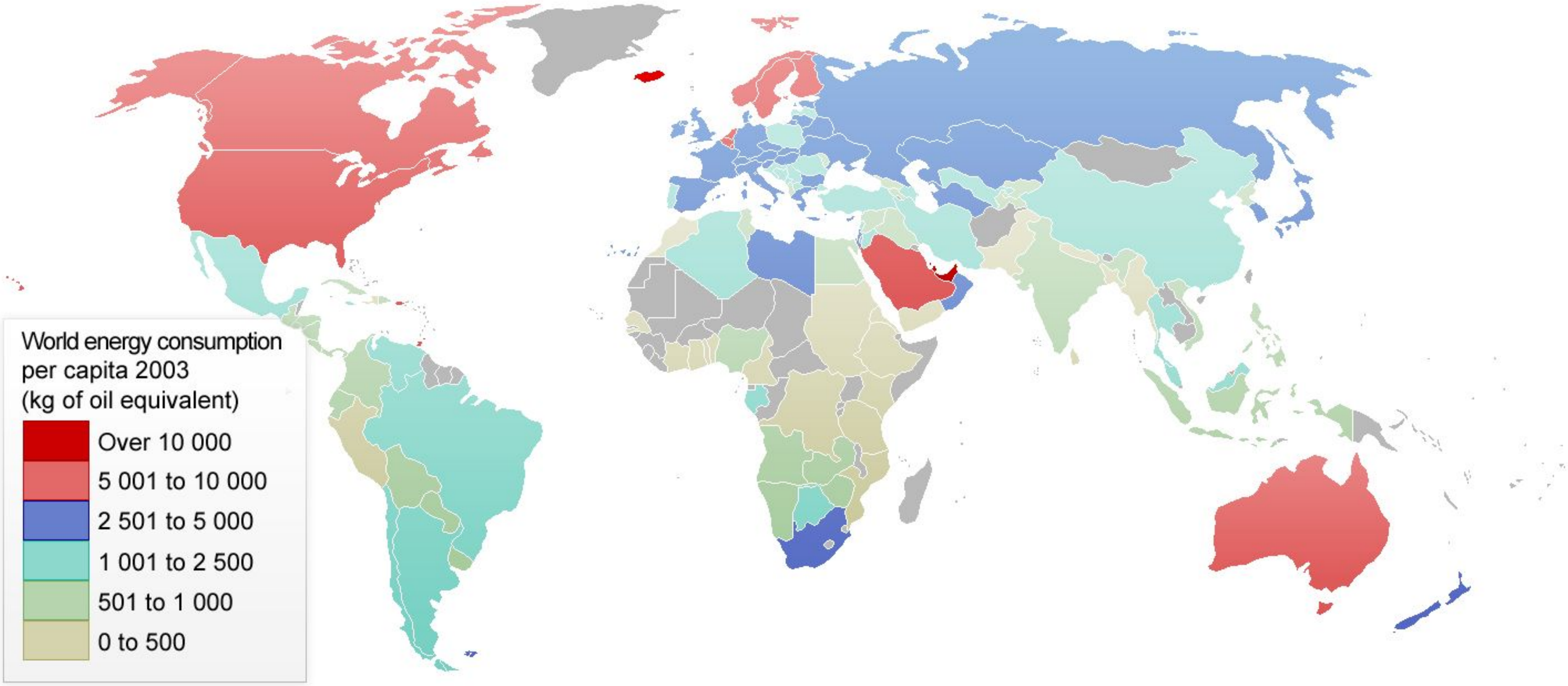
- World Consumption, **Quads** ≈ 400 (2005)
- Armenian E**nergy Consumption, Quads = 0.1752**
- **(0.0438%)**

Figure 10. World Marketed Energy Use by Fuel Type, 1980-2030



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2003* (May-July 2005), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2006).

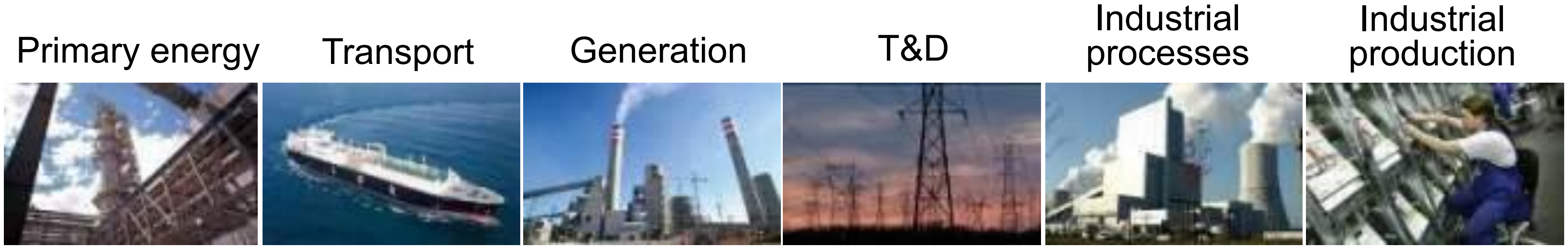
World energy consumption per capita

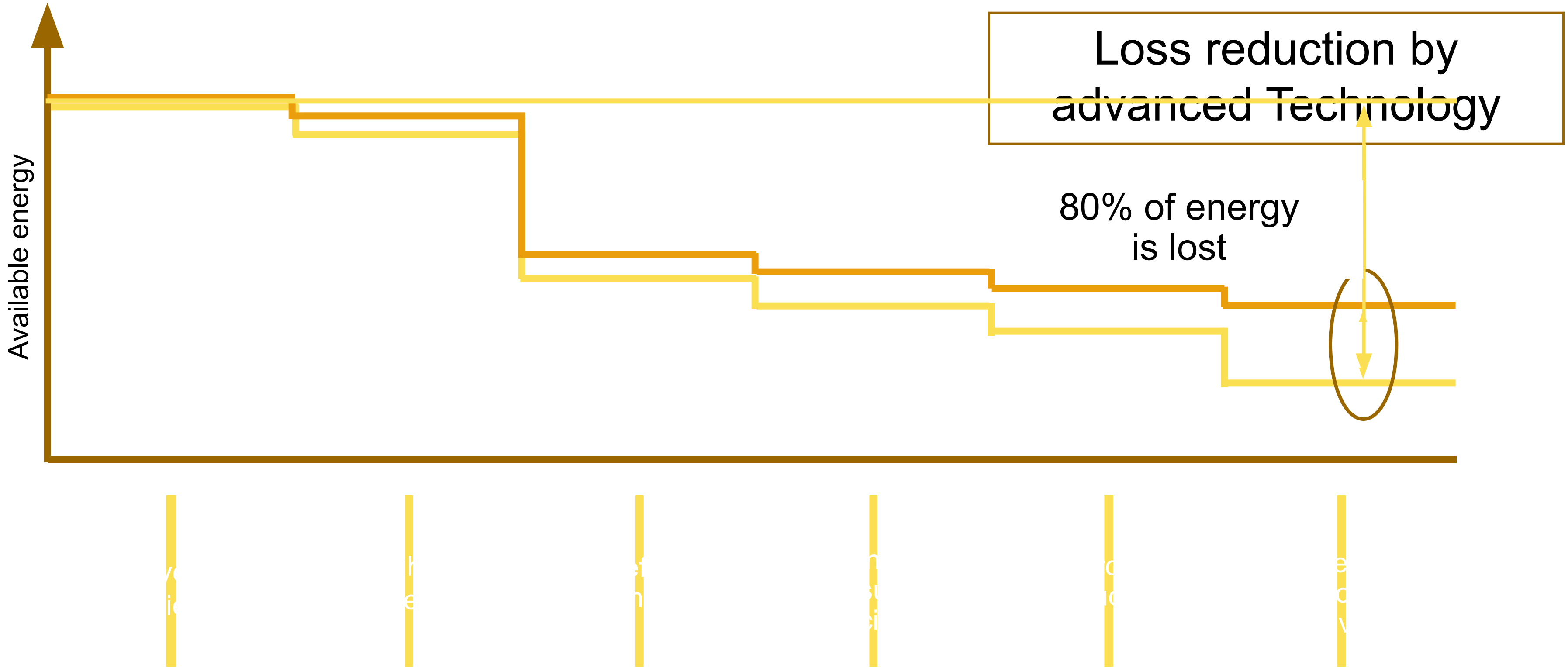


Comparison

- In 2008 energy use per person was in the USA 4.1 fold, EU 1.9 fold and Middle East 1.6 fold the world average
- and in China 87% and India 30% of the world average.
- One needs to update and verify these data…

A Look at the Electricity Value Chain



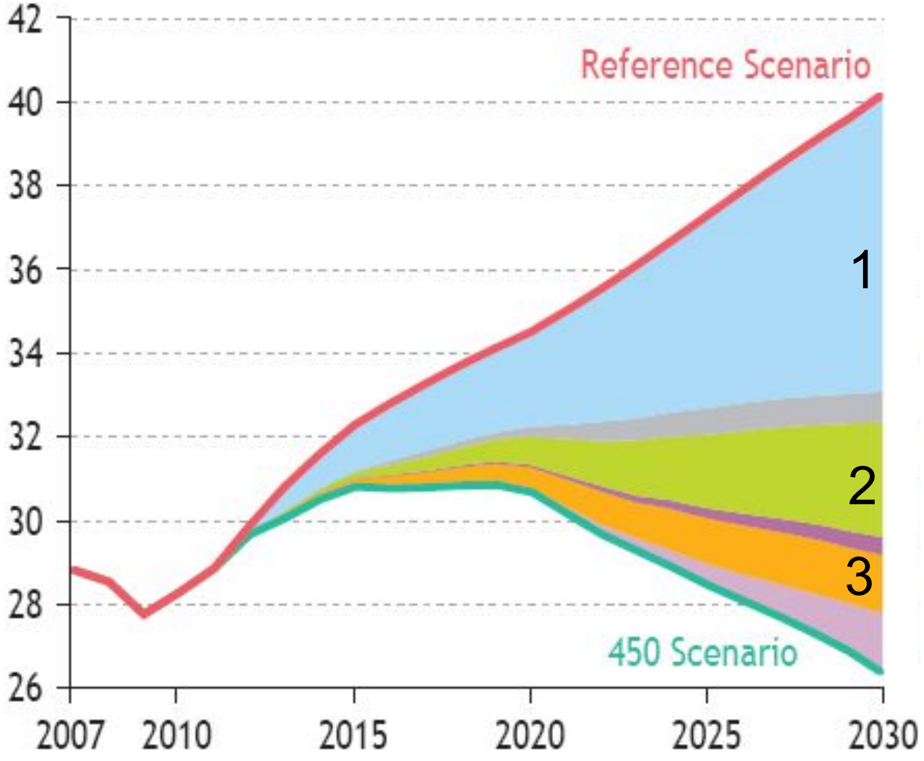


Loss reduction by advanced Technology

80% of energy is lost

World Energy-related CO2 emissions reduction

Giga ton CO_2



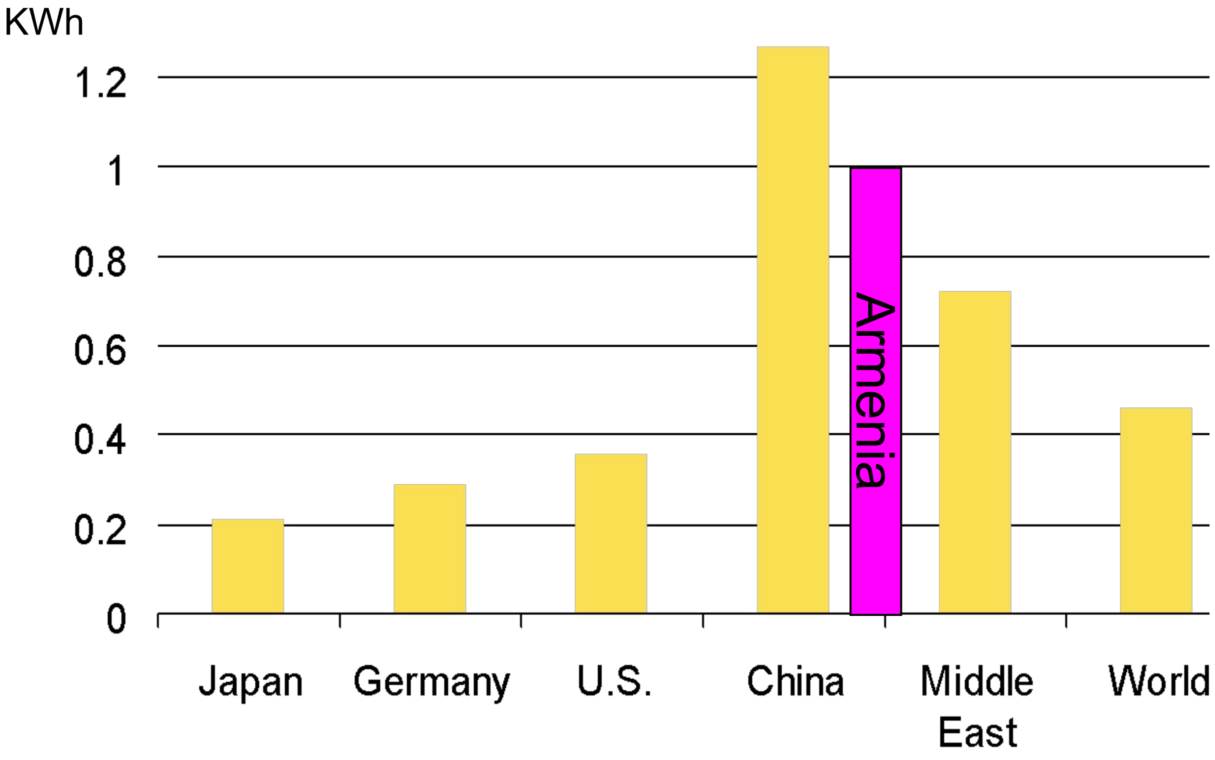
Source: international Energy Agency
www.worldenergy.com

A challenge for mature and emerging markets

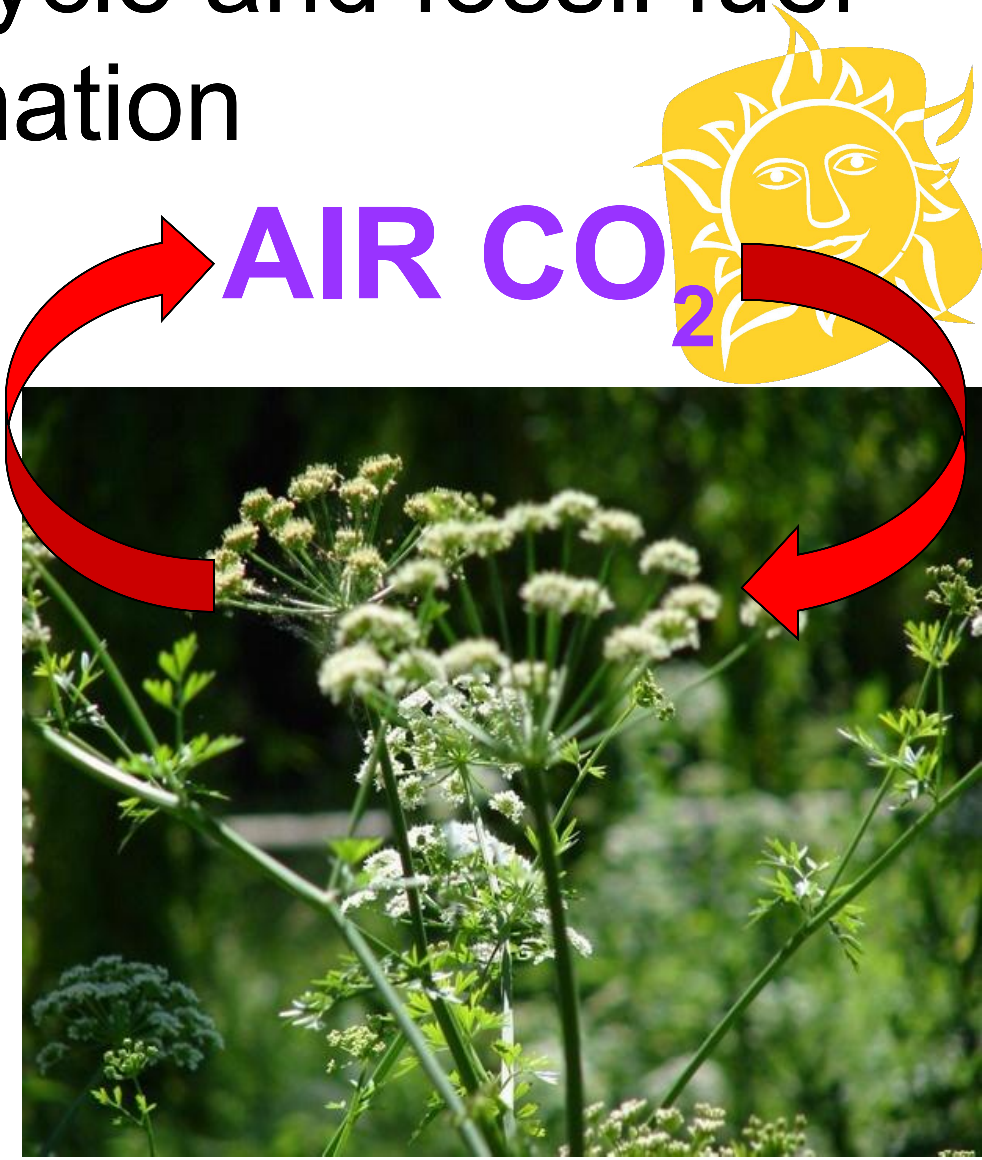
Big potential for electrical energy efficiency

Source: International Energy Agency, Key World Energy Statistics, 2008

Amount of electricity used to produce $1 of GDP



1.3 The carbon cycle and fossil fuel formation



AIR CO_2

1. Plants take CO_2 from air that contains it at 0.04% (was lower), to build carbohydrates (e.g. sugar).
2. Plants die, decompose through aerobic bacteria, returning CO_2 to the atmosphere.

1.3 The carbon cycle and fossil fuel formation

1. Plants take CO_2 from air that contains it at 0.04% (was lower), to build carbohydrates (e.g. sugar).
2. Plants die, fall and stay in water.
3. CANNOT decompose through aerobic bacteria, CANNOT return CO_2 to the atmosphere.

1.3 The carbon cycle and fossil fuel

1.3 The carbon cycle and fossil fuel formation

We have the following chain of transformations:

1. dead plant – normal conditions.
2. peat (ïáñý) – normal conditions (1mm/year). Peatlands cover a total of around 3% of global land mass or 3,850,000 to 4,100,000 km². Fossil, but can considered as slowly renewing biomass fuel.
3. lignite (brown coal) – pressure of the few layers of sediment (heat cap. 10 to 20 MJ/kg).

1.3 The carbon cycle and fossil fuel formation

Now we have the following chain of transformations, since temperature increases by 20°C - 30°C for every km of depth:

4. Coal sedimentary rocks in sedimentary basins (24 MJ/kg = 6.67 kWh/kg, 26-33 MJ/kg for Anthracite).
5. Kerogen at 50°C (1 km below the surface).
6. Oil, gas at 100°C - 150°C (3-5km of depth), > 45 MJ/kg
7. Transformation into elemental carbon through metagenesis, over 150°C, below 5 km.

1.3 The carbon cycle and fossil fuel formation

Note that every 10°C increases the rate of oil generation by a factor of two:

- 100°C (3 km): 1% of unreacted kerogen converts to oil in 1 Million years!
- 110°C (3.4 km): 2%
- 120°C (3.8 km): 4%
- 130°C (4.2 km): 8%
- 140°C (4.6 km): 16%
- 150°C (5 km): 32%

How much coal is needed to power a computer?

One can put this information to use to figure out how much coal is needed to power things. For example, running one 100 Watt computer for one year requires this much electricity:

$$100\ \text{W} \cdot 24\ \text{h} \cdot 365\ \text{days} = 876000\ \text{Wh} = 876\ \text{kWh}$$

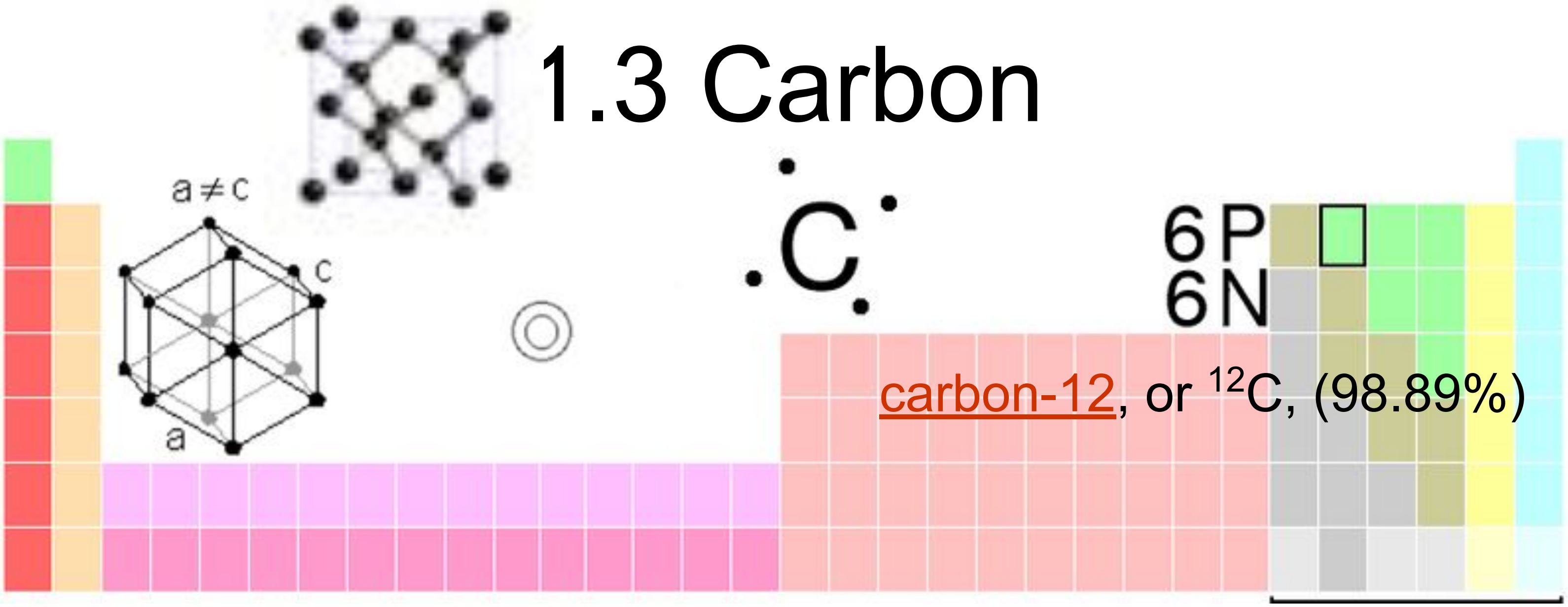
A typical Thermodynamic efficiency of coal power plants is about 30%. Of the 6.67 kWh of energy per kilogram of coal, about 30% of that can successfully be turned into electricity - the rest is waste heat.

Coal TPP-s obtain approximately 2.0 kWh electricity per kg of burned coal.

Plugging in this information one finds how much coal must be burned to power a typical computer for one year:

$$\frac{876\ \text{kW} \cdot \text{hours}}{2.0\ \text{kW} \cdot \text{hours/kg}} = 438\ \text{kg of coal} = 967\ \text{pounds of coal}$$

1.3 Carbon

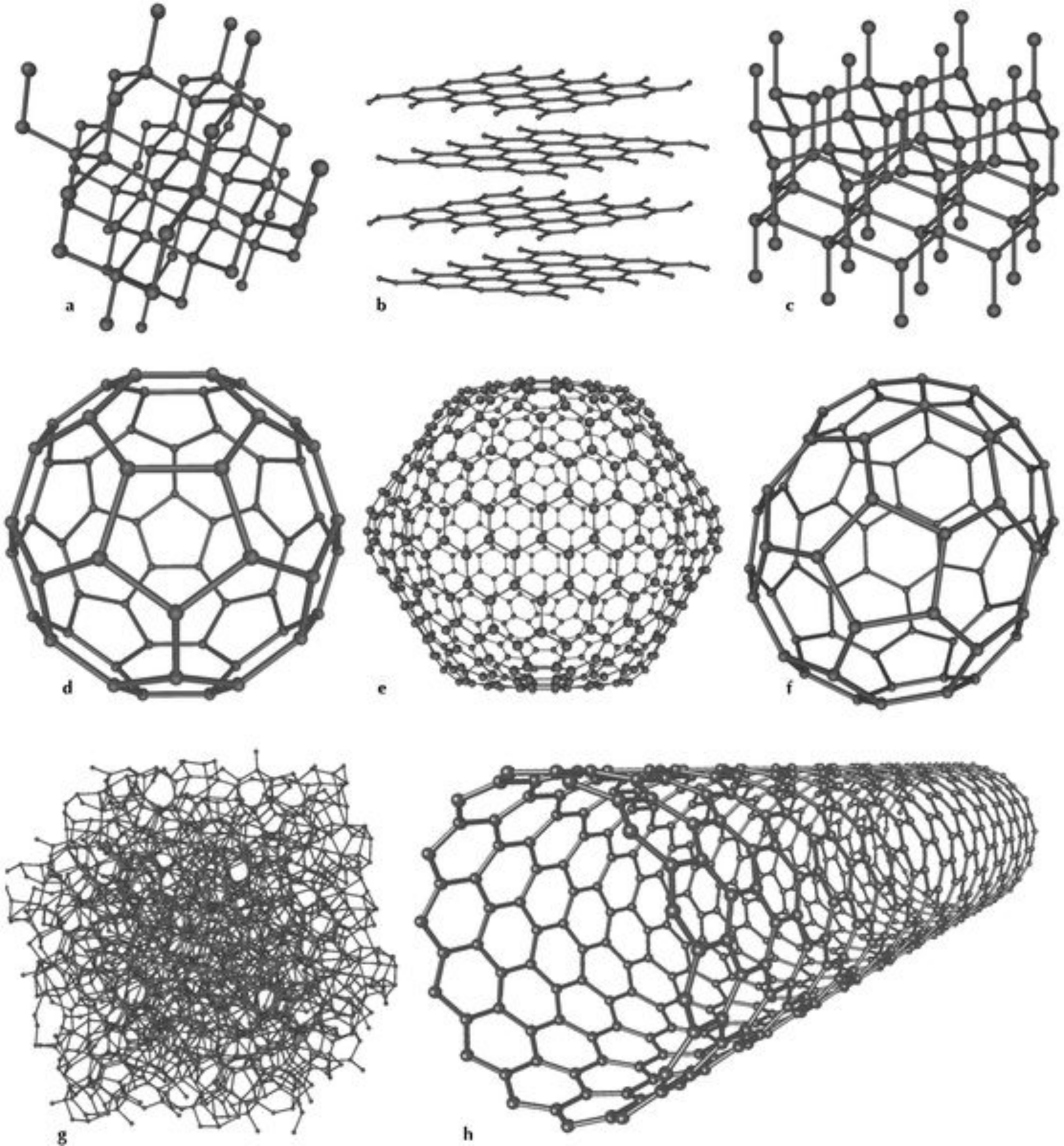


carbon-12, or ^{12}C, (98.89%)

- Carbon is the fourth most abundant chemical element in the universe by mass, after hydrogen, helium, and oxygen.
- Carbon has the ability to form long, indefinite chains with interconnecting C-C bonds. This property is called catenation. This property allows carbon to form an infinite number of compounds;
- in fact, there are more known carbon-containing compounds than all the compounds of the other chemical elements combined except those of hydrogen (because almost all carbon compounds contain hydrogen).

Eight allotropes of carbon - crystal structure

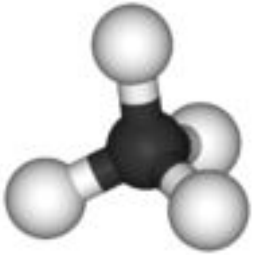
1. Diamond,
2. Graphite,
3. Lonsdaleite,
4. C60,
5. C540,
6. C70,
7. Amorphous carbon
8. Carbon nanotube.



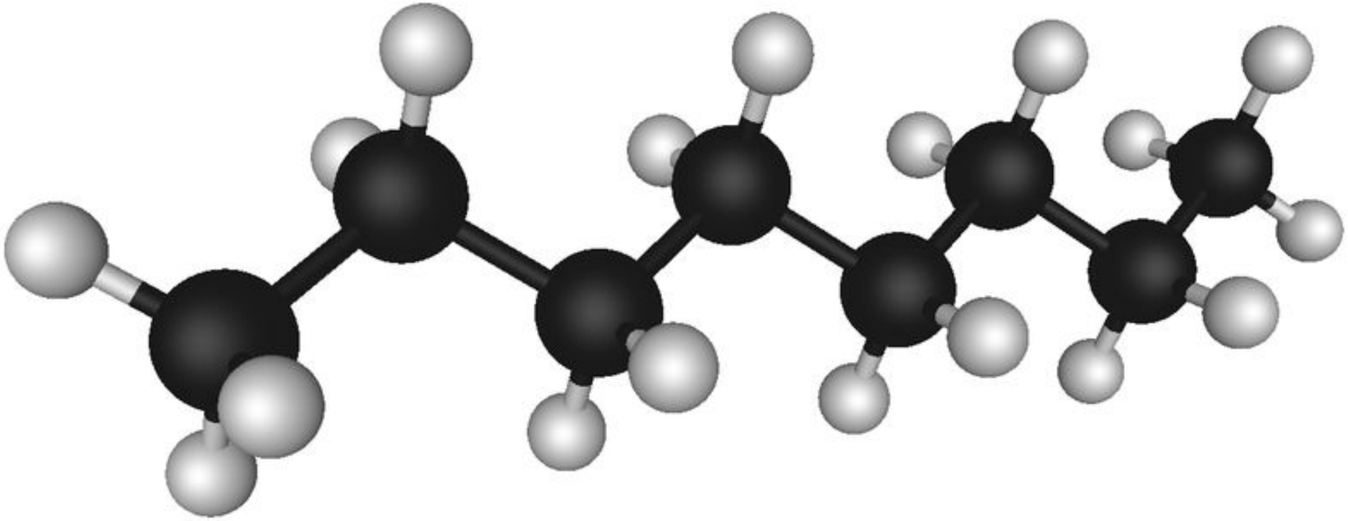
Hydrocarbons

on coal *rank*, with higher rank coals containing less hydrogen, oxygen and nitrogen, until 95%

Hydrocarbon chains



- CH_4 – methane (55.5 MJ/kg, 0.717kg/m^3)
- C_3H_8 – propane (48.9 MJ/kg)
- C_8H_{18} - 2,2,4-Trimethylpentane – gasoline (46 MJ/kg, H_2 – 141.9 MJ/kg)
- C_xH_y – general formula for hydrocarbons
- C_nH_{2n+2} – alkanes (petroleum)



Burning Hydrocarbons

Generally, the chemical equationGenerally, the chemical equation for stoichiometricGenerally, the chemical equation for stoichiometric burning of hydrocarbon in oxygen is as follows:

$$C_xH_y + (x + \frac{y}{4})O_2 \rightarrow xCO_2 + (\frac{y}{2})H_2O$$

For example, the burning of propane is:

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

The simple word equation for the combustion of a hydrocarbon in oxygen is:

$$\text{Fuel} + \text{Oxygen} \rightarrow \text{Heat} + \text{Water} + \text{Carbon dioxide}$$

Or, for example: $C_8H_{18} + 12.5\ O_2 \rightarrow 8CO_2 + 9H_2O + \text{heat}$ (for 2,2,4-Trimethylpentane)

1.3 The carbon cycle and fossil fuel formation

Because coal is at least 50% carbon (by mass), then 1 kg of coal contains at least 0.5 kg of carbon, which is $\frac{0.5\text{kg}}{12 \cdot \text{kg}/\text{kmol}} = \frac{1}{24}\text{kmol}$ where 1 mol is equal to N_A (*Avogadro Number, = 6.022* $\cdot 10^{23} \text{mol}^{-1}$) particles. This combines with oxygen in the atmosphere during combustion, producing carbon dioxide, with an atomic weight of ($12 + 16 \cdot 2$ = mass(CO_2) = 44 kg/kmol). $\frac{1}{24}\text{kmol}$ of CO_2 is produced from the $\frac{1}{24}\text{kmol}$ present in every kilogram of coal, which once trapped in CO_2 weighs approximately $\frac{1}{24}\text{kmol} \cdot \frac{44\text{kg}}{\text{kmol}} = \frac{11}{6}\text{kg} \approx 1.83\text{kg}$.

This fact can be used to put a carbon-cost of energy on the use of coal power. Since the useful energy output of coal is about 30% of the 6.67 kW-h/kg(coal), we can say about **2 kWh/kg(coal) of energy is produced**.

Remember!

- Since 1 kg coal roughly translates as 1.83 kg of CO_2, we can say that using electricity from coal produces CO_2 at a rate of about

  0.915 kg(CO_2) / kWh,

  or about

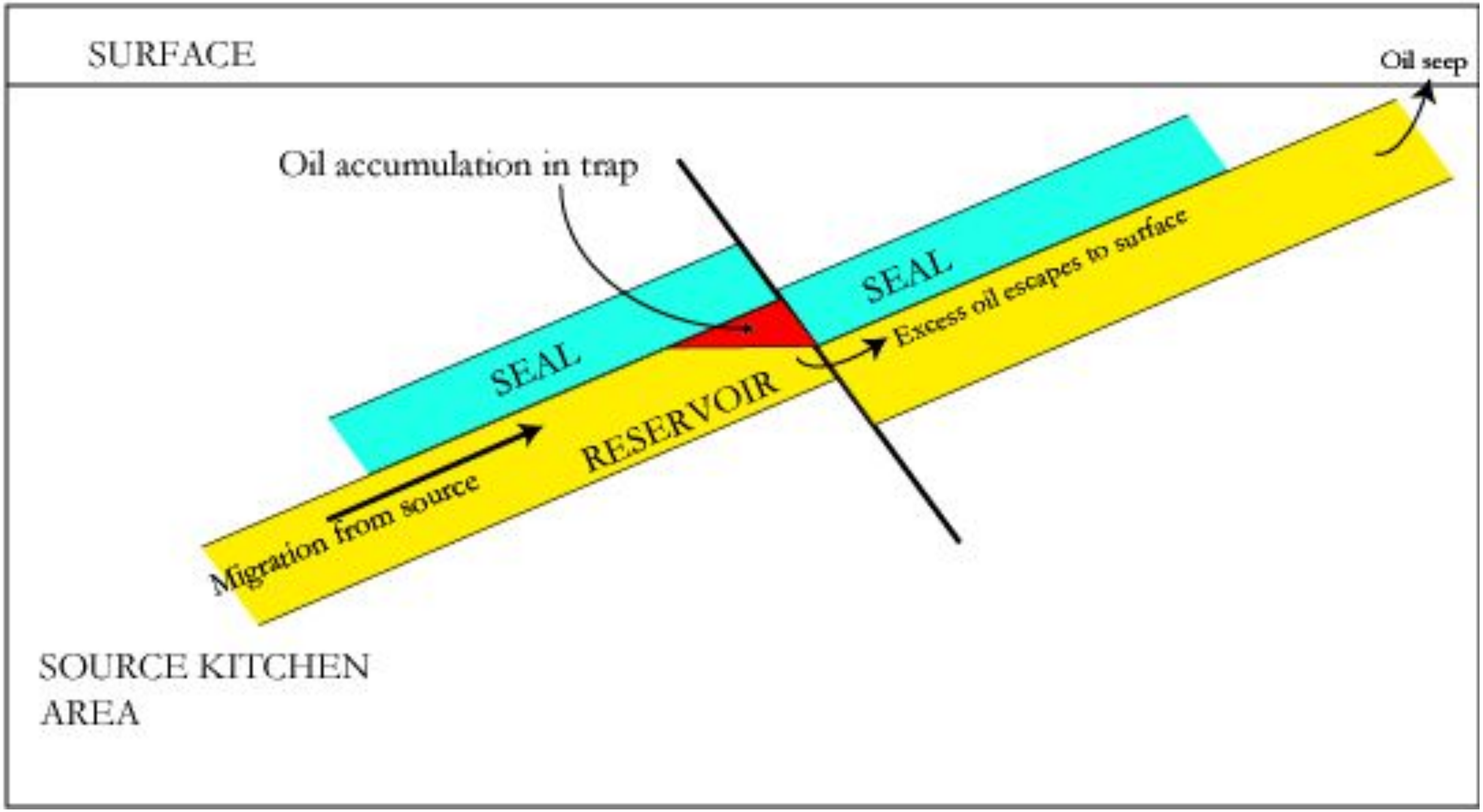
  0.254 kg(CO_2) / MJ.

Shale (Ã»ñÃ³ù³ñ)

Oil shale is a general term applied to a group of rocks rich enough in organic material (kerogen) to yield petroleum upon distillation. The kerogen in oil shale can be converted to oil through the chemical process of pyrolysis. During pyrolysis the oil shale is heated to 445-500 °C in the absence of air and the kerogen is converted to oil and separated out, a process called "retorting".

Reservoir Rock

- An oil reservoir, petroleum system or petroleum reservoir is often thought of as being an underground "lake" of oil, but it is actually composed of hydrocarbons contained in porous rock formations.
- Structural traps are formed by a deformation in the rock layer that contains the hydrocarbons (e.g., fault traps and **anticlinal** traps).


SURFACE
Oil seep
Oil accumulation in trap
SEAL
SEAL
Excess oil escapes to surface
RESERVOIR
Migration from source
SOURCE KITCHEN AREA

1.3 Economy of extraction

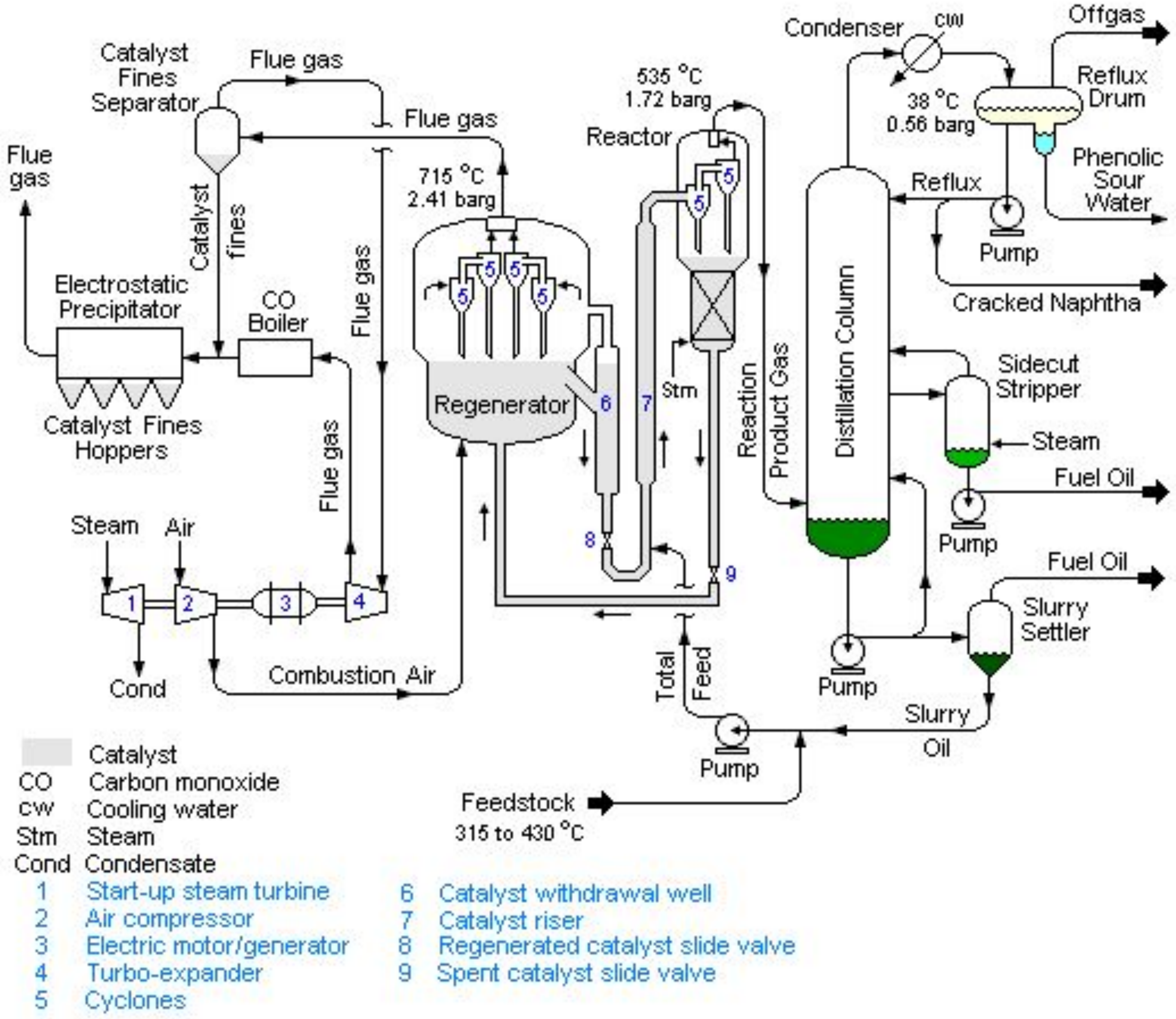
- Porosity = Volume of Void / Total Volume of Rock
- Permeability = interconnectedness between the pores (compare with conductivity vs. resistivity in conductors)
- Sedimentary Rocks

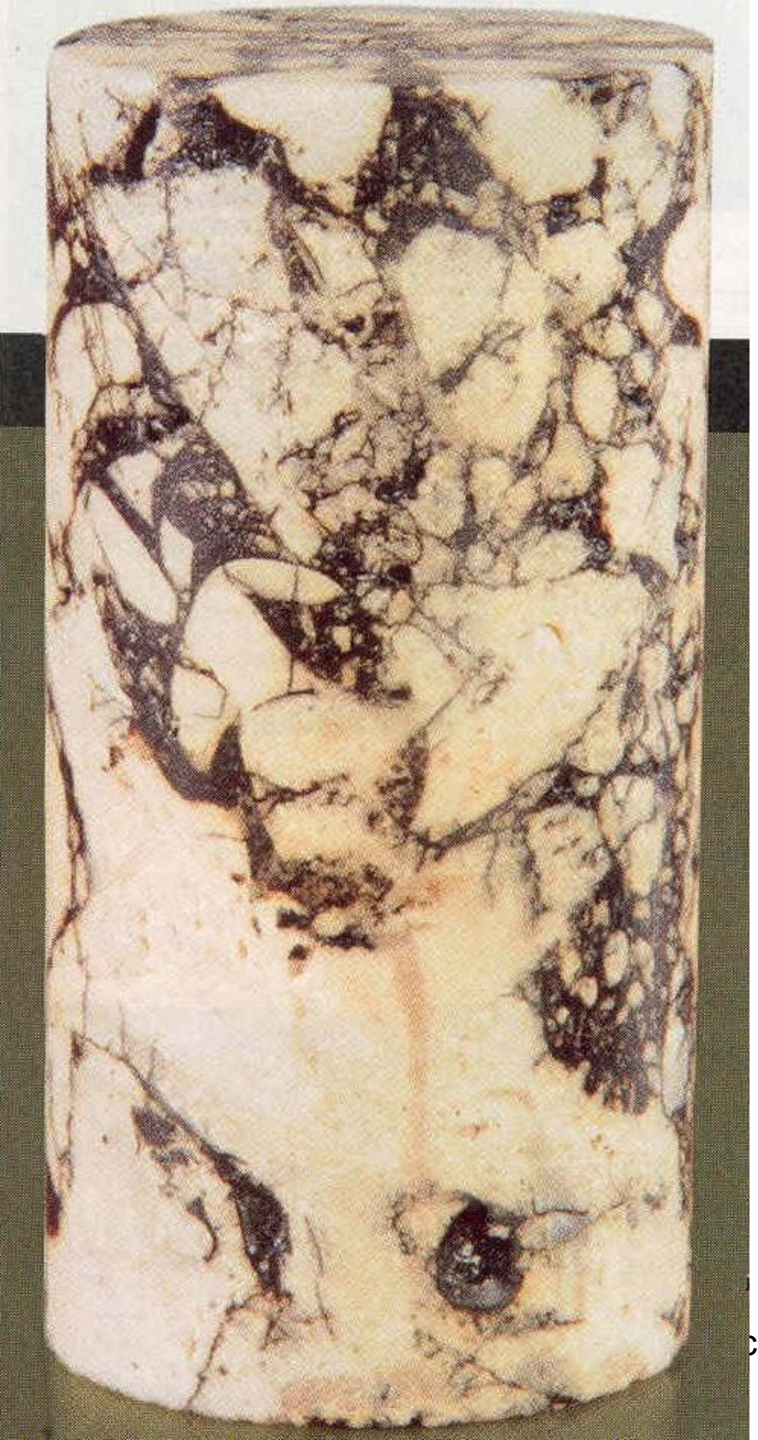
Liquid fuel volume units

- The standard **barrel** of crude oil or other petroleum product (abbreviated bbl) is **42** US gallons (34.972 Imperial gallons or **158.987** L).
- **1 Gallon = 3.8 Liters**.
- This measurement originated in the early Pennsylvania oil fields, and permitted both British and American merchants to refer to the same unit, based on the old English wine measure, the tierce.

Oil extraction – gulf of Mexico

Oil refinery - cracking


Catalyst Fines Separator
Flue gas
Flue gas
Flue gas
Catalyst fines
Electrostatic Precipitator
CO Boiler
Flue gas
Flue gas
Catalyst Fines Hoppers
Steam
Air
1
2
3
4
Cond
Combustion Air
715 °C
2.41 barg
5
5
5
5
Regenerator
6
7
8
9
535 °C
1.72 barg
Reactor
5
5
Stm
Reaction Product Gas
Total Feed
Pump
Feedstock
315 to 430 °C
Condenser
cw
38 °C
0.56 barg
Offgas
Reflux Drum
Phenolic Sour Water
Reflux
Pump
Cracked Naphtha
Distillation Column
Sidecut Stripper
Steam
Fuel Oil
Pump
Fuel Oil
Slurry Settler
Pump
Slurry Oil
Catalyst
CO Carbon monoxide
cw Cooling water
Stm Steam
Cond Condensate
1 Start-up steam turbine
2 Air compressor
3 Electric motor/generator
4 Turbo-expander
5 Cyclones
6 Catalyst withdrawal well
7 Catalyst riser
8 Regenerated catalyst slide valve
9 Spent catalyst slide valve

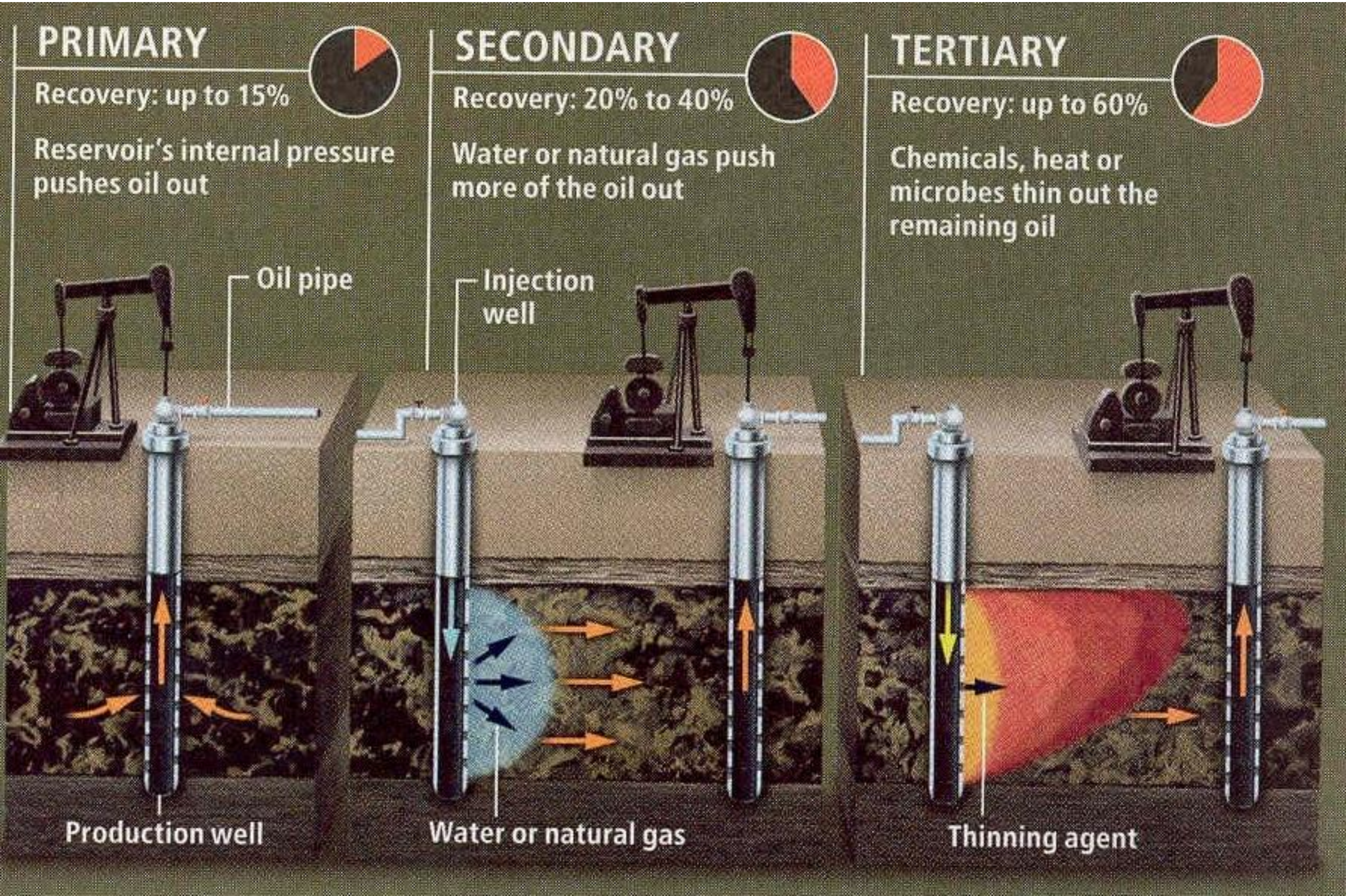


Oil soaked porous rock. Sample comes from offshore fields near Sicily that are too expensive to exploit with current technology

1.4 Ultimate recovery of non-renewable resources

- Reserves vs. Resources □
- Discovered vs. Expected.
- Role of technology for:
- Discovering the non-renewable resources;
- Extraction.

Oil extraction technologies



PRIMARY

Recovery: up to 15%

Reservoir's internal pressure pushes oil out

SECONDARY

Recovery: 20% to 40%

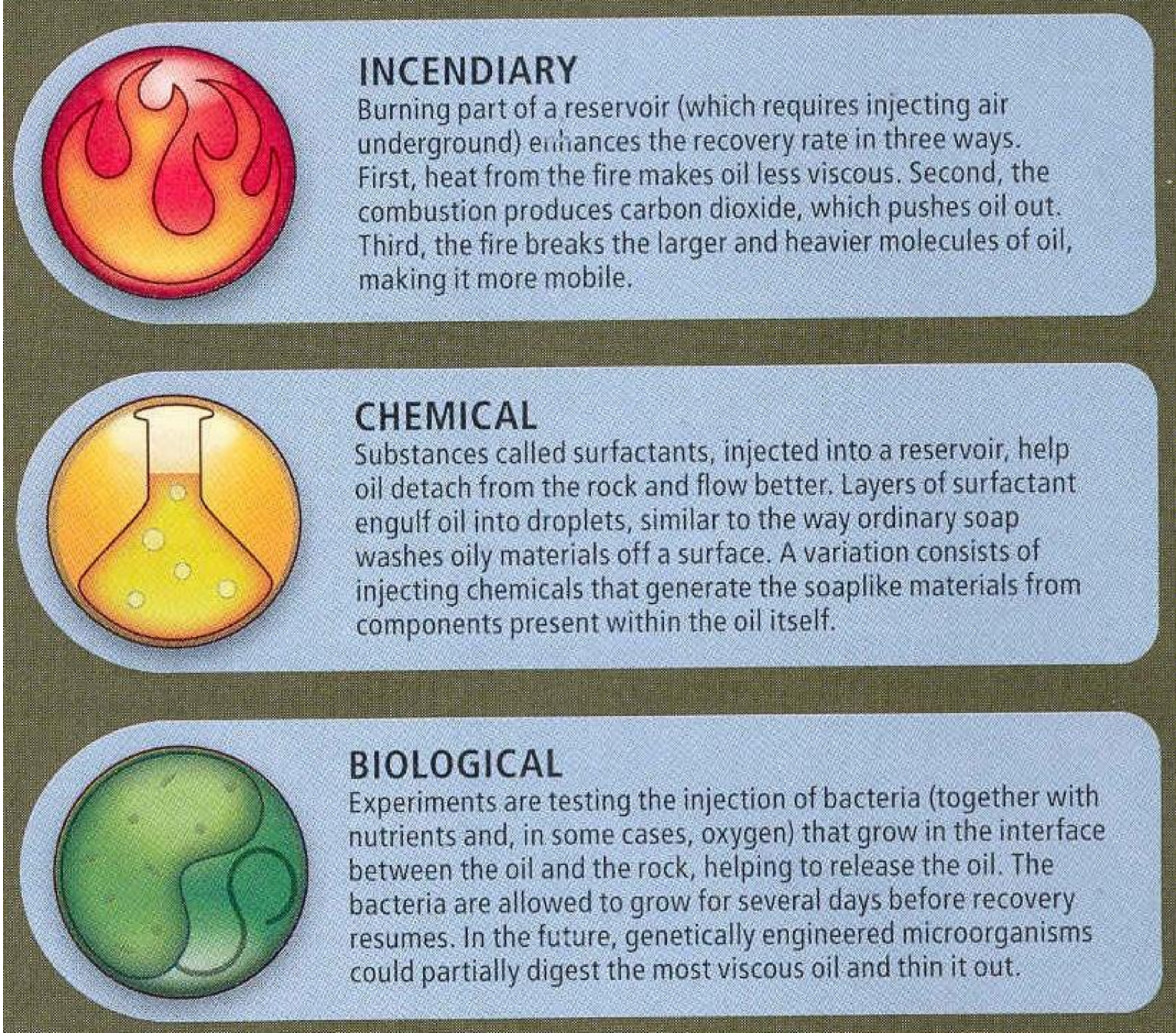
Water or natural gas push more of the oil out

TERTIARY

Recovery: up to 60%

Chemicals, heat or microbes thin out the remaining oil

More oil extraction technologies



INCENDIARY

Burning part of a reservoir (which requires injecting air underground) enhances the recovery rate in three ways. First, heat from the fire makes oil less viscous. Second, the combustion produces carbon dioxide, which pushes oil out. Third, the fire breaks the larger and heavier molecules of oil, making it more mobile.

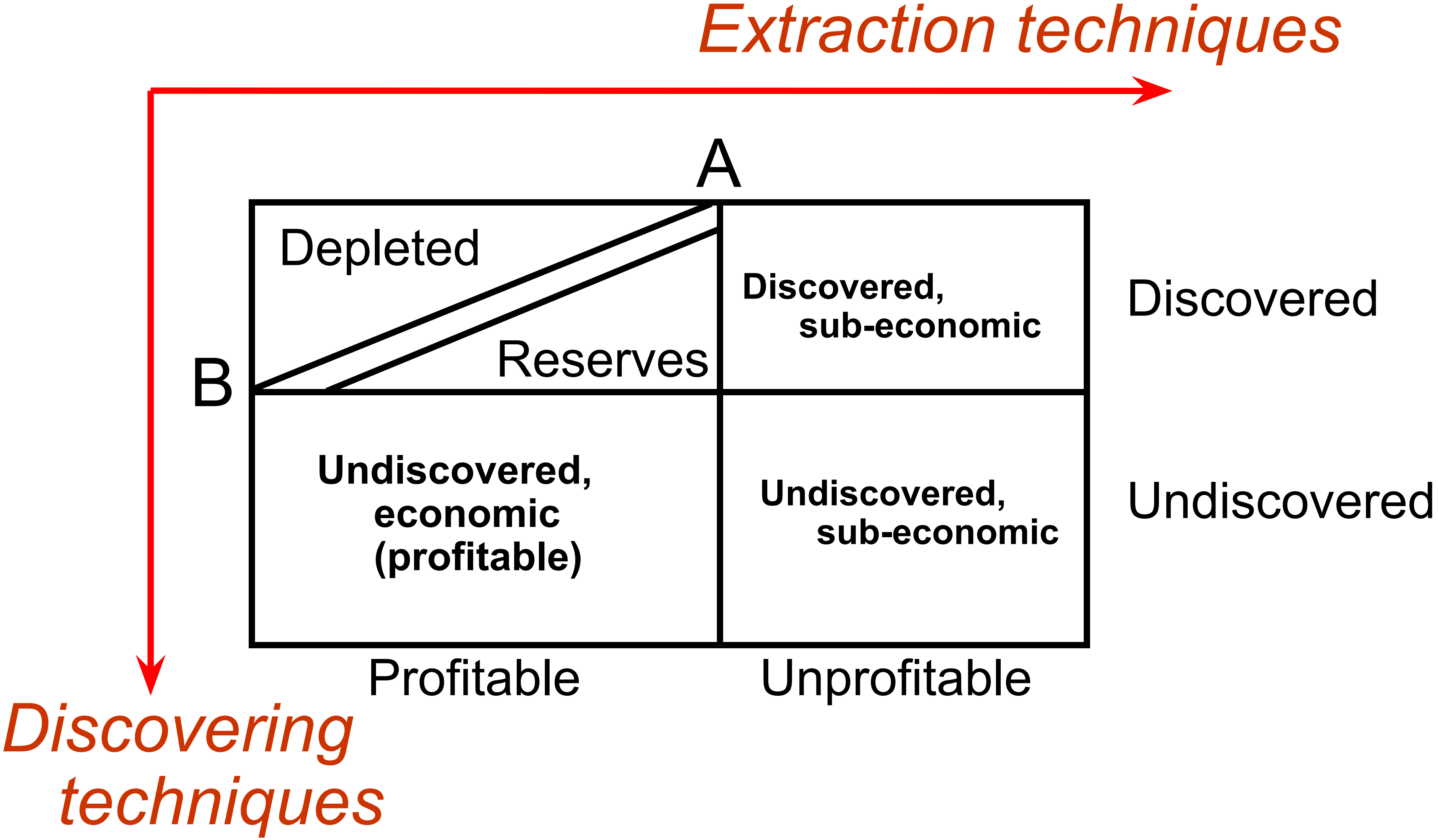
CHEMICAL

Substances called surfactants, injected into a reservoir, help oil detach from the rock and flow better. Layers of surfactant engulf oil into droplets, similar to the way ordinary soap washes oily materials off a surface. A variation consists of injecting chemicals that generate the soaplike materials from components present within the oil itself.

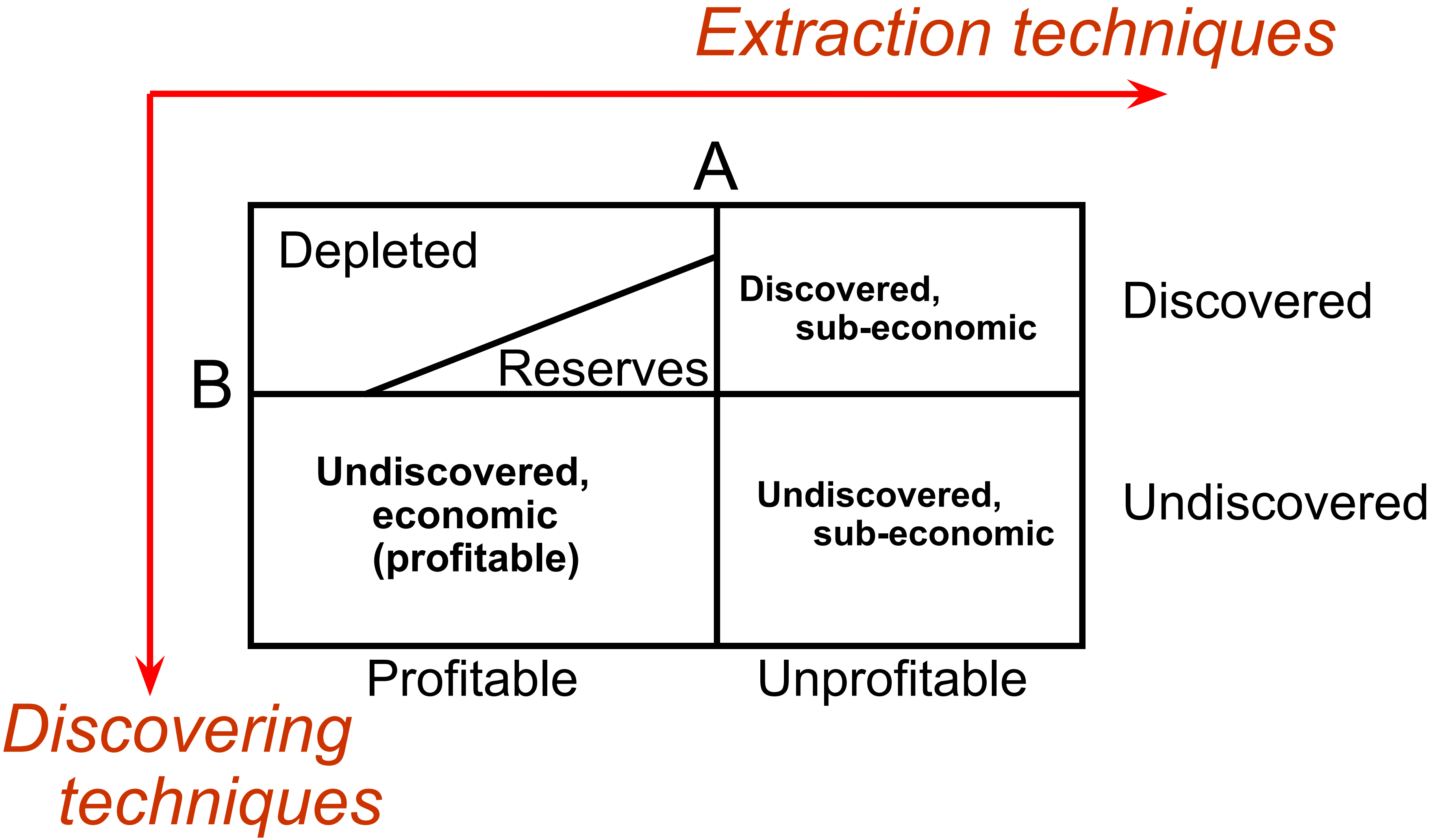
BIOLOGICAL

Experiments are testing the injection of bacteria (together with nutrients and, in some cases, oxygen) that grow in the interface between the oil and the rock, helping to release the oil. The bacteria are allowed to grow for several days before recovery resumes. In the future, genetically engineered microorganisms could partially digest the most viscous oil and thin it out.

1.4 Ultimate recovery of non-renewable resources



1.4 Ultimate recovery of non-renewable resources



Extraction techniques

A

B

Depleted

Reserves

Discovered, sub-economic

Discovered

Undiscovered, economic (profitable)

Undiscovered, sub-economic

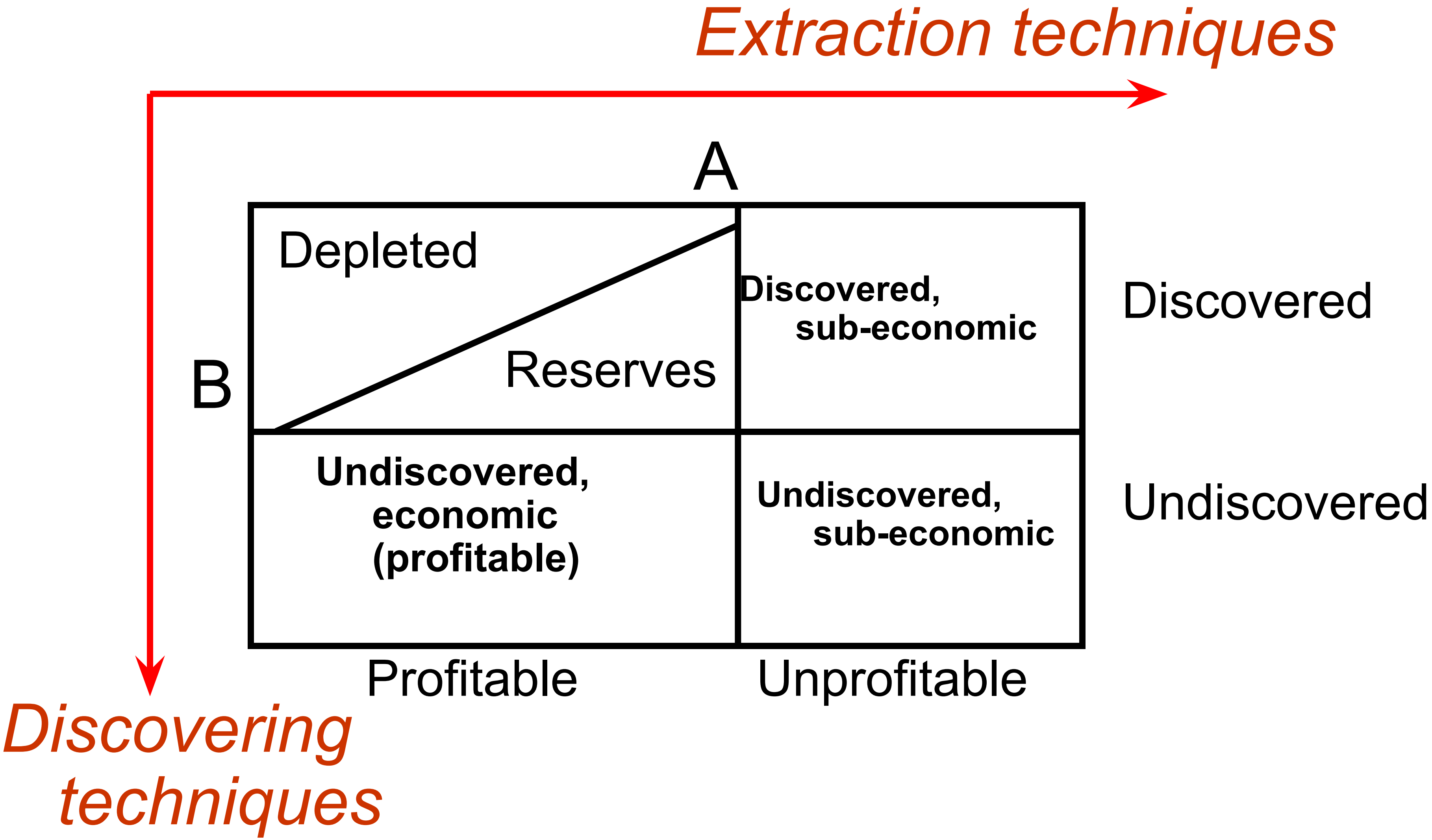
Undiscovered

Profitable

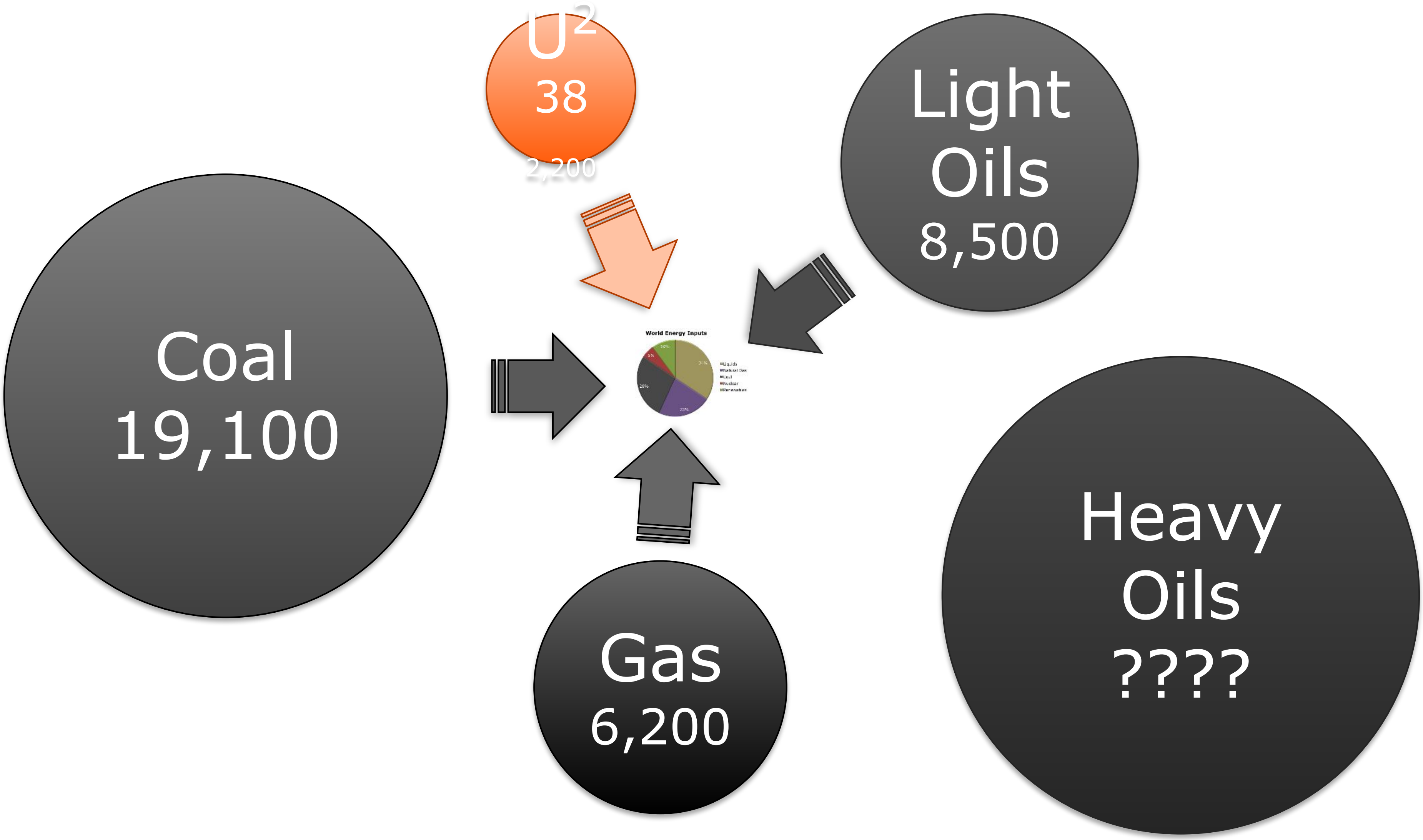
Unprofitable

Discovering techniques

1.4 Ultimate recovery of non-renewable resources



Consumable Energy Reserves
>36,000 Quads



U^{2}
38
2,200

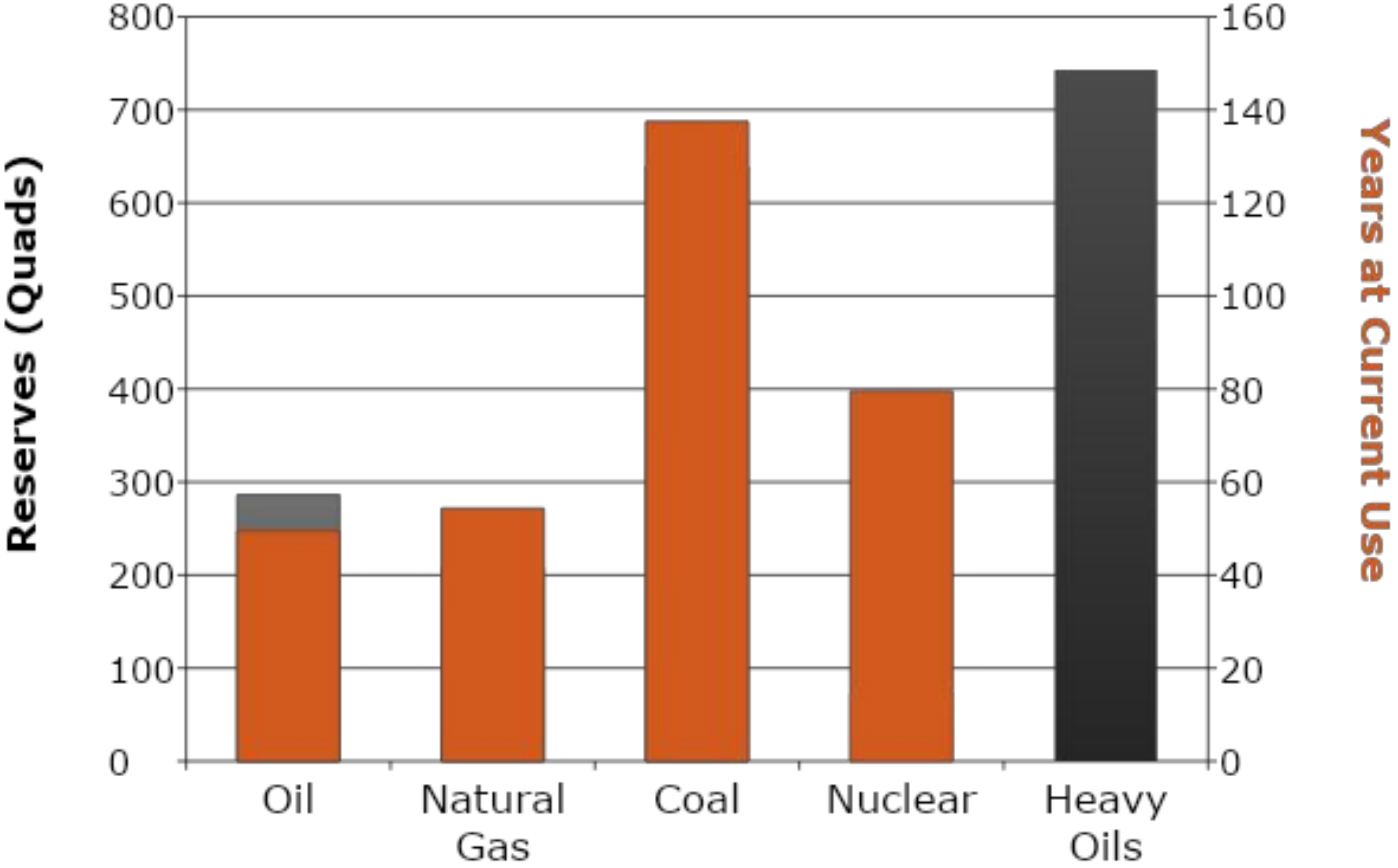
Light
Oils
8,500

Coal
19,100

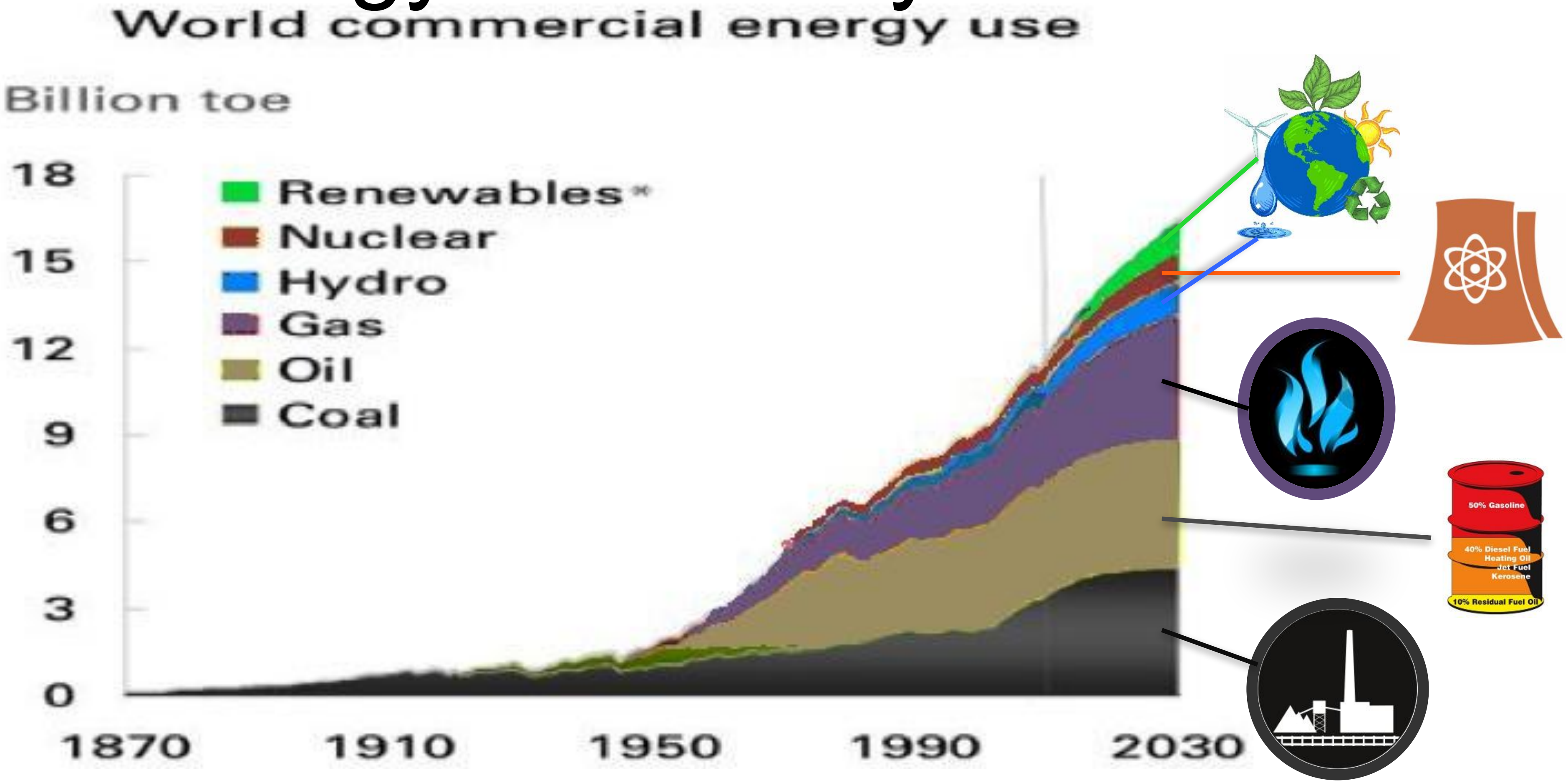
Gas
6,200

Heavy
Oils
????

Consumable Energy Reserves

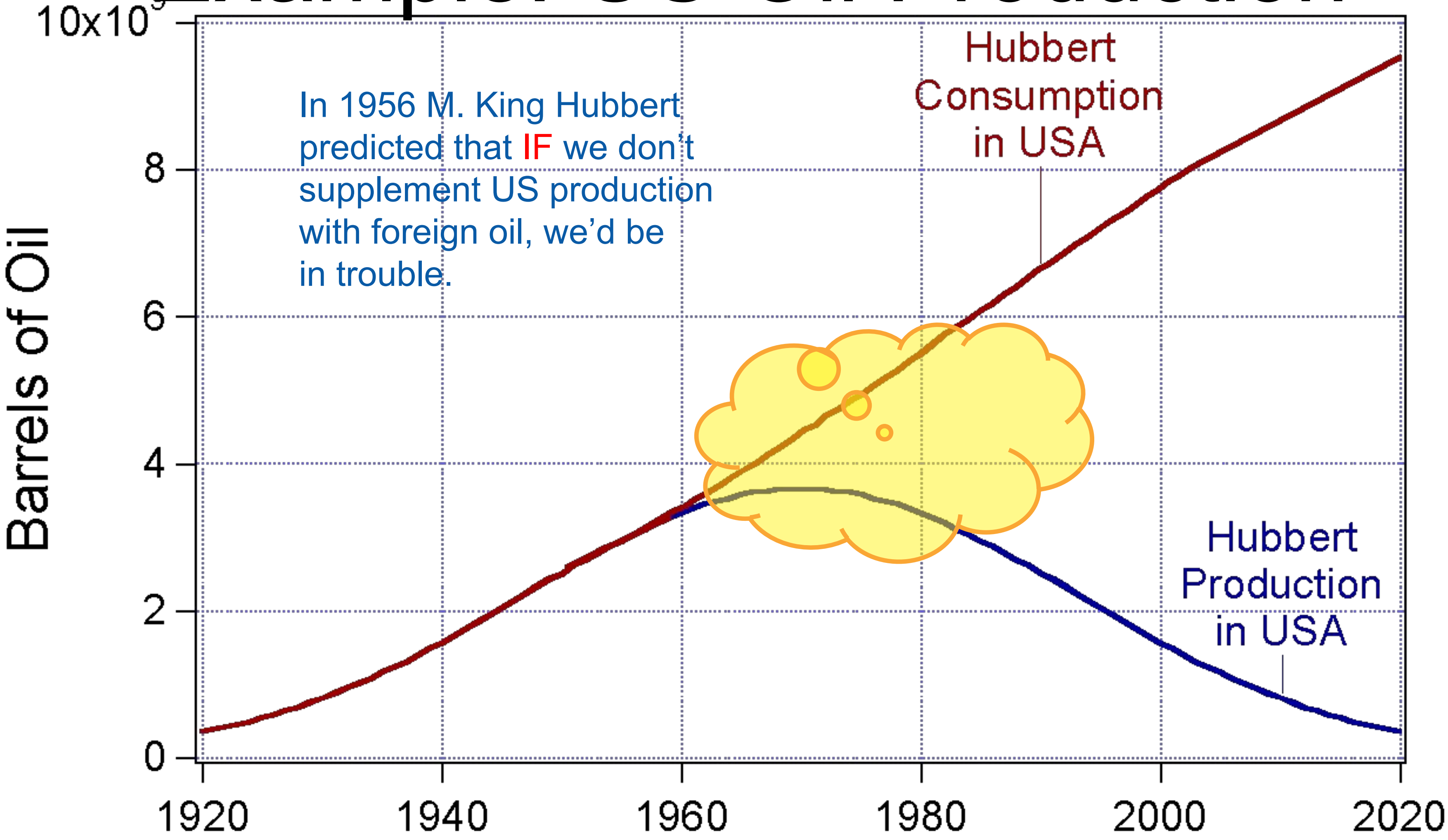


Energy Use Always Increases



Does “**Current Consumption**” Exist?
Are reserves infinite?

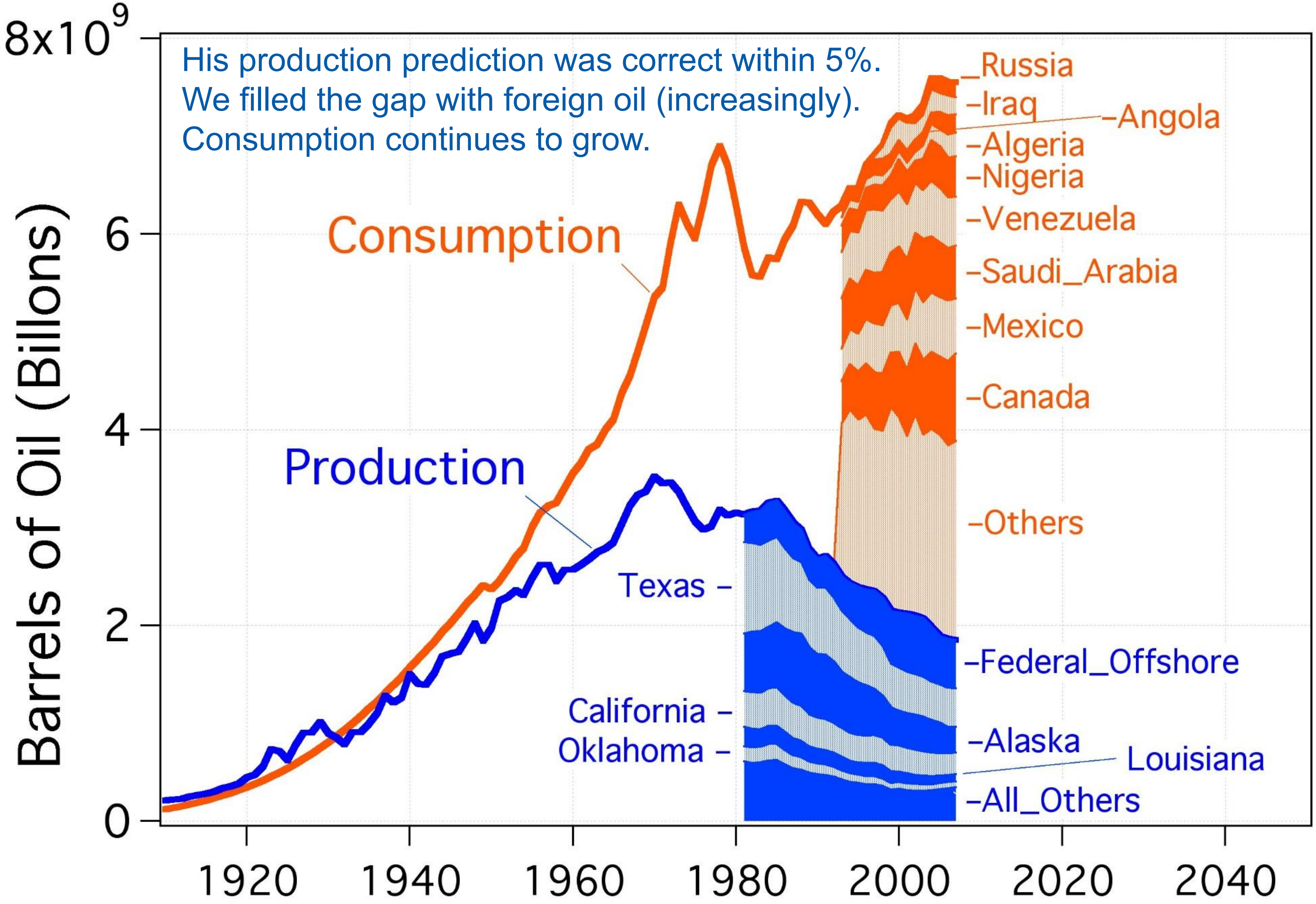
Example: US Oil Production



In 1956 M. King Hubbert predicted that IF we don't supplement US production with foreign oil, we'd be in trouble.

Adapted from 1956 data presented by M. King Hubbert
to Spring Meeting of the Southern District, API

What Happened?



His production prediction was correct within 5%.
We filled the gap with foreign oil (increasingly).
Consumption continues to grow.

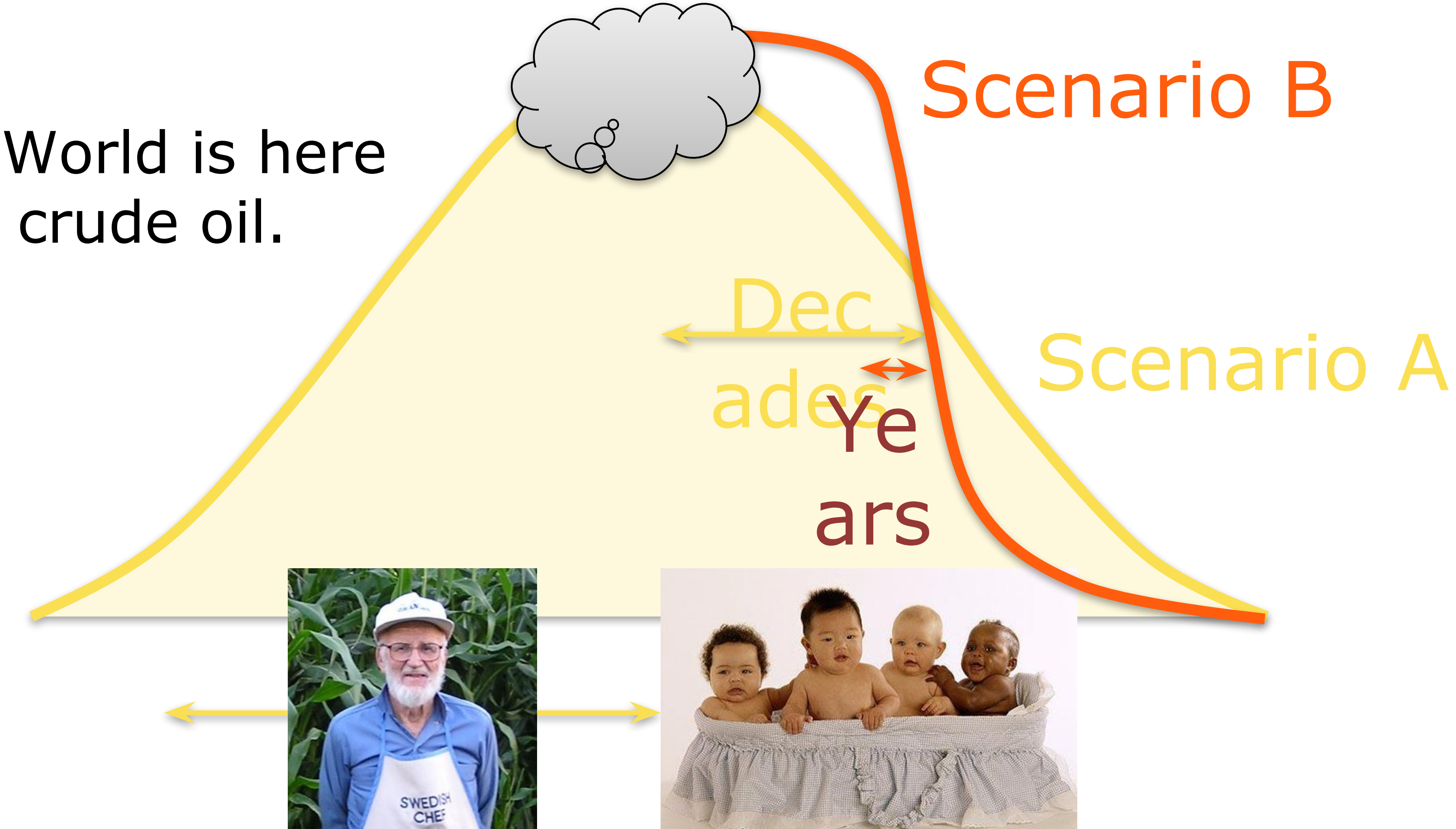
"Our ignorance is not so vast as our failure to use what we know."

M. King Hubbert

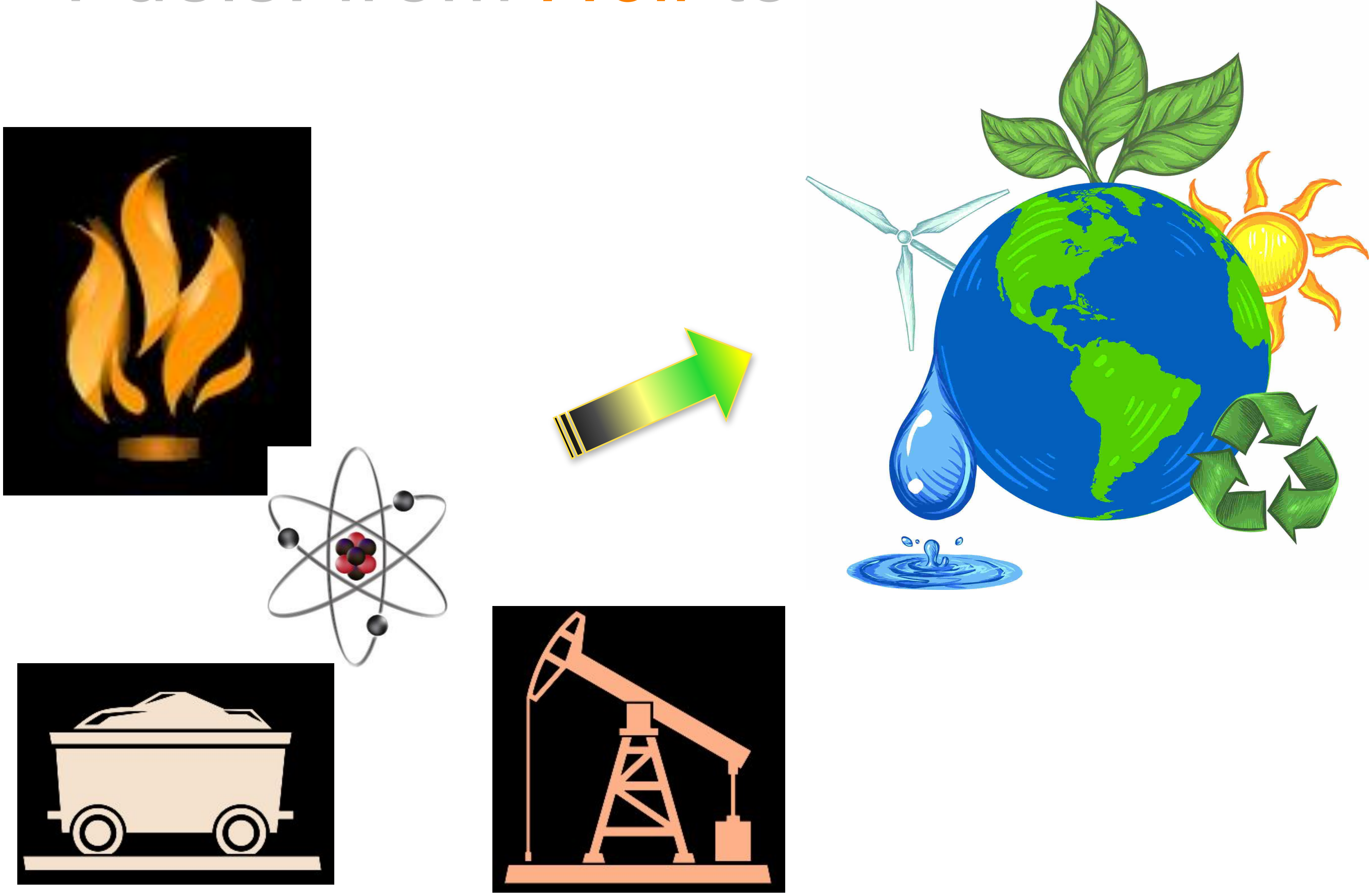
Importance of “Peak Oil”

1) Resource in the ground is fixed (area under curve)
2) Extraction past the peak dictates transition time
3) It takes decades to transition to new technologies

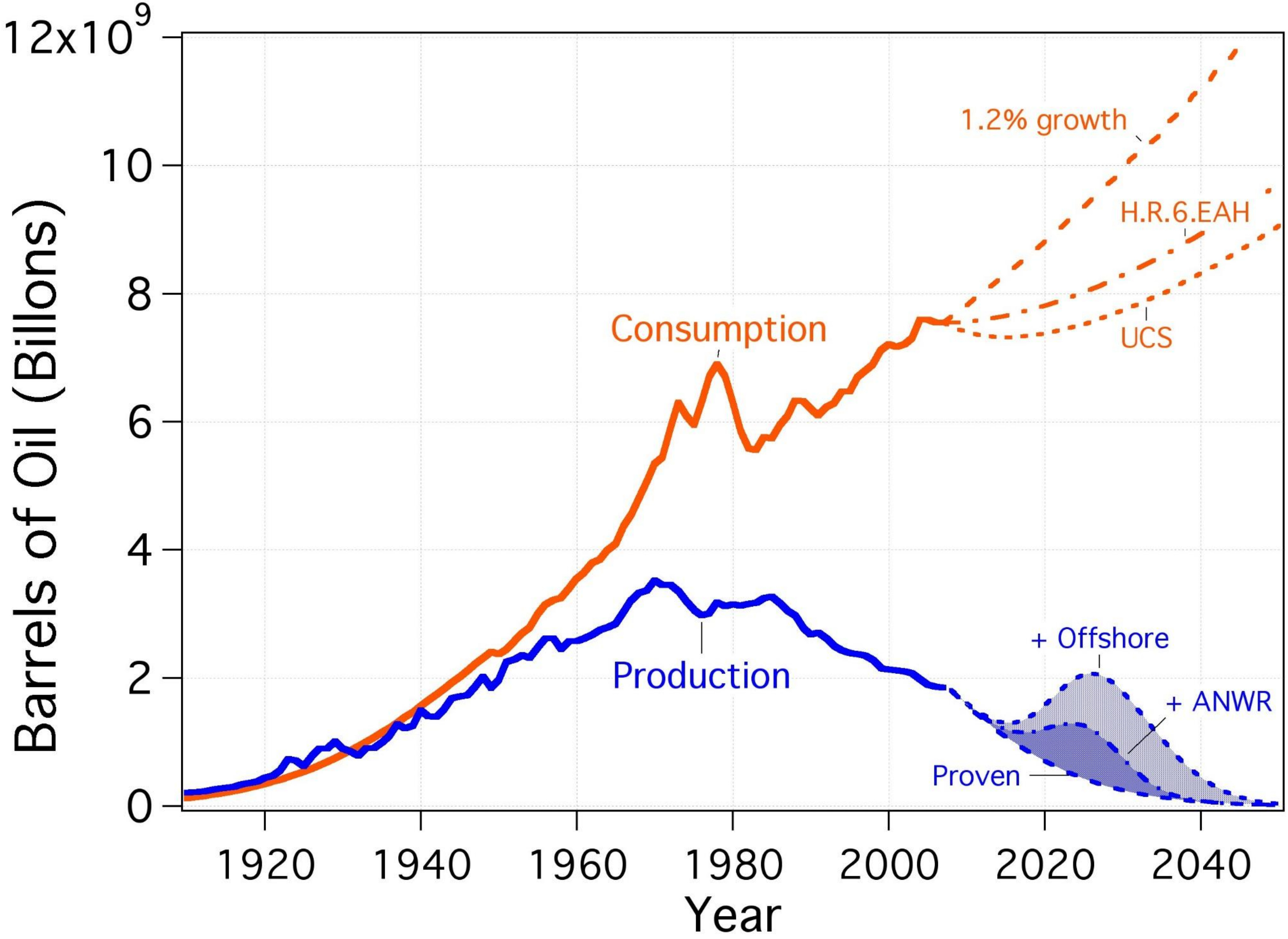
The World is here
with crude oil.



Fuels: from *Hell* to **Heaven**



US Oil Remaining



1.5 The future of energy resources

- Solar Constant = 1366 W/sq.m.
- Sahara's surface area = 9,000,000 sq.m.
- If we use 10% of Sahara with 10% efficiency, we will get 800 Exajoules/year!
- This is twice as much as current world consumption.
- I can see the future «Ocean Solar Power Plants», that produce Hydrogen!
- However, population grows exponentially!

The World of Water, Kindzadza

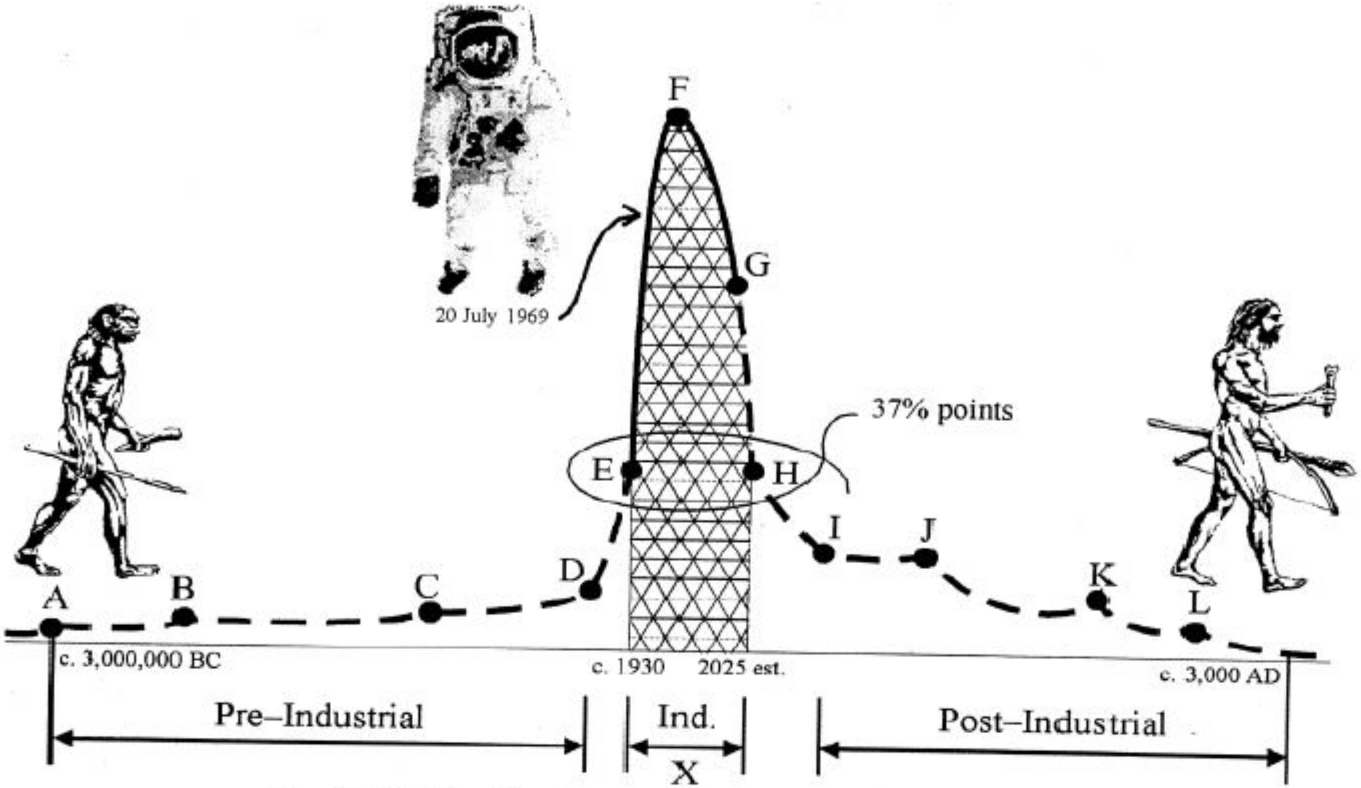


Fig. 8-15. The short span of Industrial Civilization.

Source: "The Coming Oil Crisis", C.J. Campbell

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Remember This Guy?

Oil money funded *his* attack on the United States.

Never Again!

This company can help triple domestic oil production — and help us kick OPEC to the curb for good!

Homework, Case study

- Shaten’s book, page 16, problems 1,2,3.