THE FUTURE OF COAL

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INTRODUCTION

WHAT IS THE FUTURE OF COAL?

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Possible answers to this question:

1. There is no future. We must stop burning coal and other fossil fuels as soon as we can.
2. The future will be a continuation of the present: Large uses of coal for electricity generation and metallurgy (coke), and possible uses for synthetic fuels.
3. Coal has a very good future, but it will not be like the past or present.

WHAT WILL AFFECT THE FUTURE OF COAL?

Two factors will have a large impact on the future of coal:

1. New supplies of petroleum and natural gas released by hydraulic fracturing (“fracking”) of shale.
2. The contribution of CO_2 to global climate change.

HYDRAULIC FRACTURING “FRACKING”

Fracking breaks rocks that contain petroleum or natural gas.

Releases petroleum or gas and allows it to flow to the well.

Makes large amounts of oil and gas available that could not be recovered by traditional methods.

EFFECTS OF FRACKING

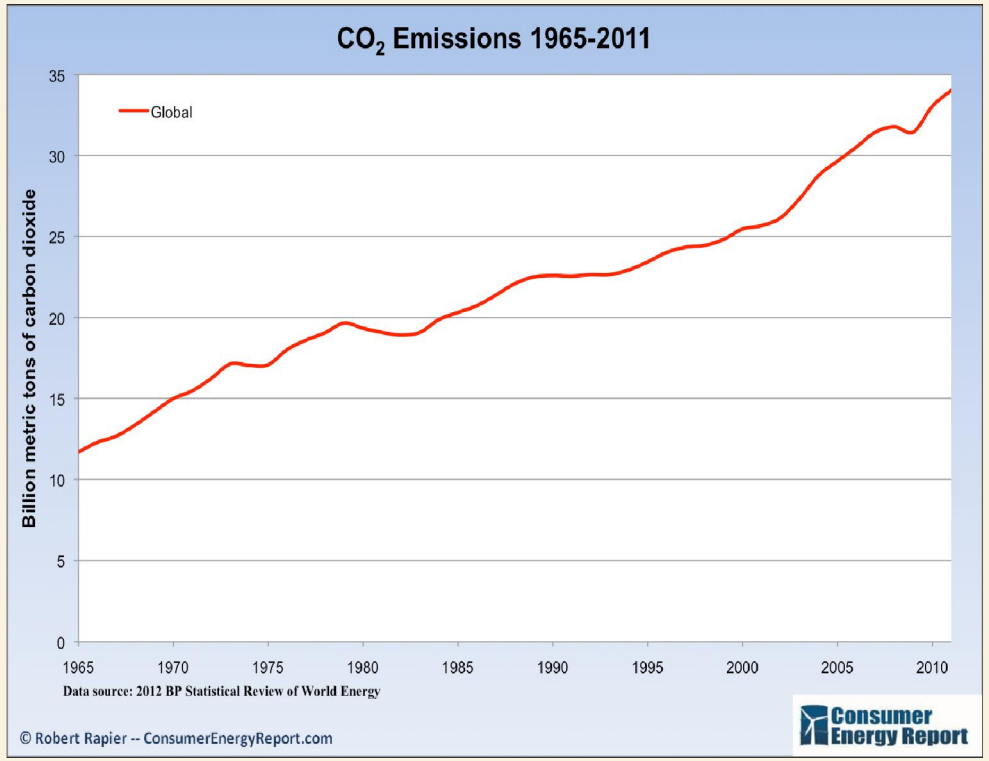
In some countries, including the U.S.A., amounts of natural gas and petroleum released by fracking have changed the economy.

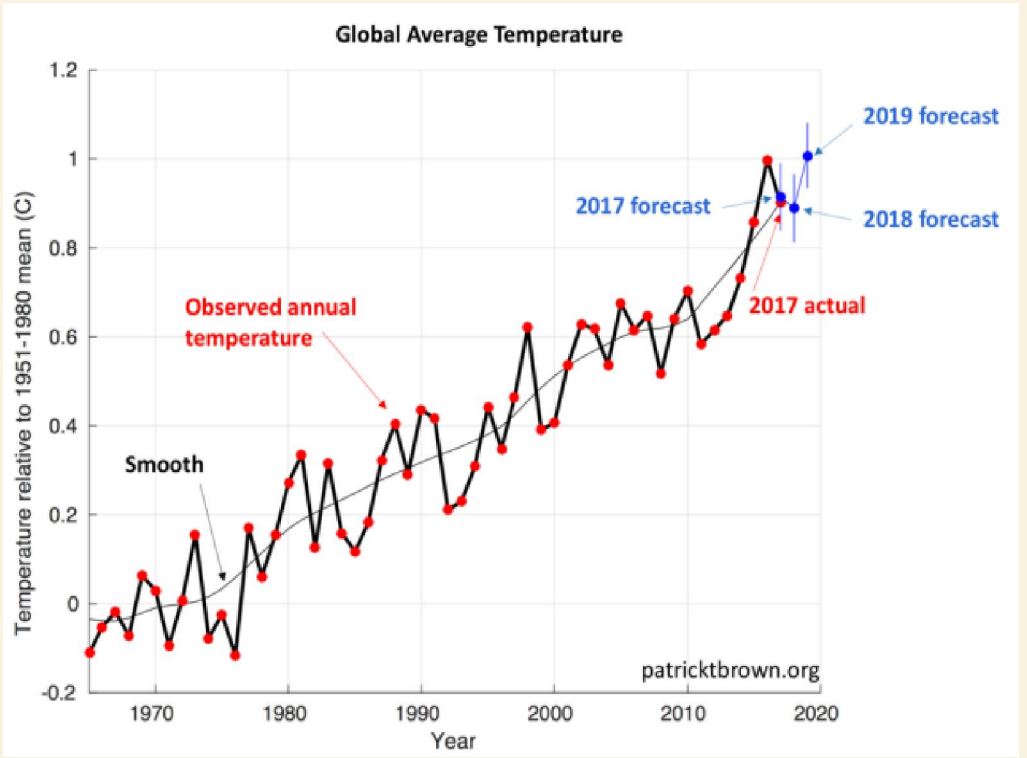
Gas and petroleum can be exported instead of imported. There is now less interest in coal liquefaction and gasification.

Natural gas has replaced coal as the main fuel for electricity generation.

But: not all countries permit fracking.

CO_2 EMISSIONS AND AVERAGE GLOBAL TEMPERATURE





CO_2 FROM FOSSIL FUELS

Emissions (kg CO_2/GJ) show that coal produces the most CO_2 per unit of useful energy.

Natural gas	53
Petroleum (fuel oil, diesel)	75
Bituminous coal	93

SOME FACTS TO REMEMBER

- ✓ CO_2 is not the only greenhouse gas.
- ✓ Human activities are not the only source of CO_2 emissions.
- ✓ Coal combustion is not the only human activity that produces CO_2.

WHAT TO DO ABOUT COAL AND CO_2?

1. Stop using coal at once.
2. Do nothing. There is no problem.
3. Continue using coal as we do, but increase efficiency and with CO_2 capture and storage.
4. Do not burn coal. Use it as a carbon material and as a source of chemicals.

MY MESSAGE

- ✓ The worst thing we can do with coal is to burn it.
- ✓ Coal is too valuable as a carbon material and as a source of chemicals.
- ✓ Let us all work together to find new ways of using coal that help people and do not cause pollution.

EXAMPLE 1.

FOOD AND WATER

EVERY PERSON NEEDS FOOD AND WATER.

Coal can help us to obtain both food and clean, safe water. Examples:

- Activated carbon made from coal can help to purify water.
- Coal can be used to help to grow plants.

ACTIVATED CARBON

Activated carbon is a highly porous form of amorphous carbon, with very large surface area. It is used to adsorb substances from liquid or gas streams.

Activated carbons can be made from almost any carbonaceous material, such as coals, wood, and agricultural wastes (example: olive or cherry stones).

Many grades and forms of activated carbons are made, depended on the intended use.

MAKING ACTIVATED CARBON FROM COAL

Two strategies for activated carbon from coal:

- Physical activation. Reaction with steam or CO_2.
- Chemical activation. Reaction with strong acid or base removes parts of the coal structure. Examples: H_3PO_4, $ZnCl_2$ or KOH.

Properties of activated carbon depend on the coal used and on the reaction conditions of activation.

PHYSICAL ACTIVATION OF COAL

Uses the same reactions as in gasification:

$$C + H_2O \rightarrow H_2 + CO$$

$$C + CO_2 \rightarrow 2\ CO$$

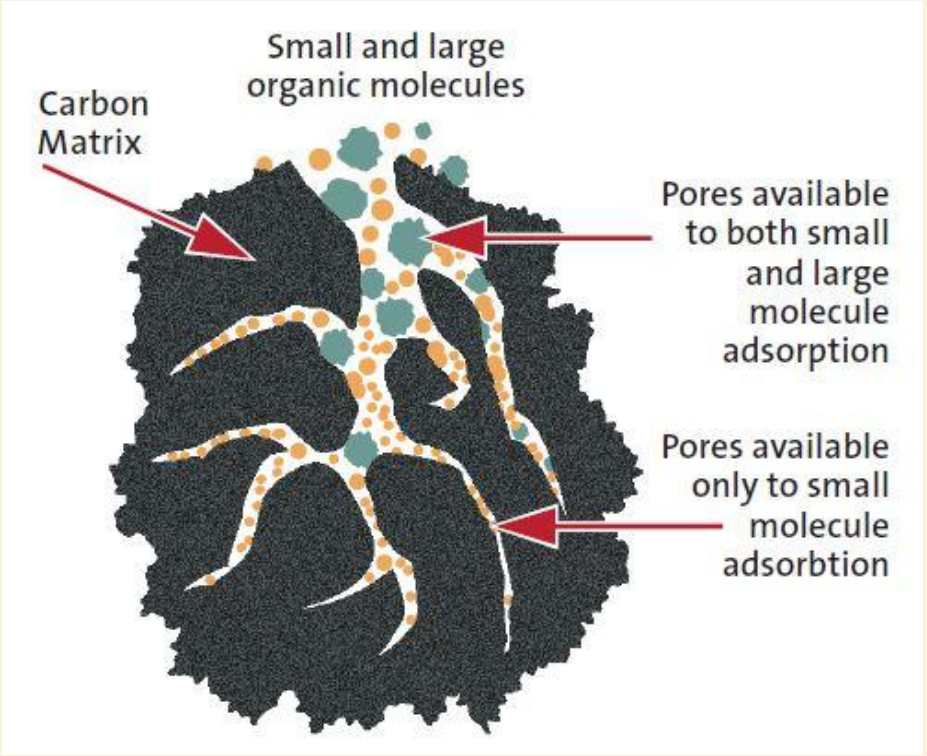
Only a portion of the coal is converted to CO.

The loss of carbon atoms as CO causes the pores in coal to become larger and increases total surface area.

HOW ACTIVATED CARBON WORKS

Adsorption onto activated carbon depends on

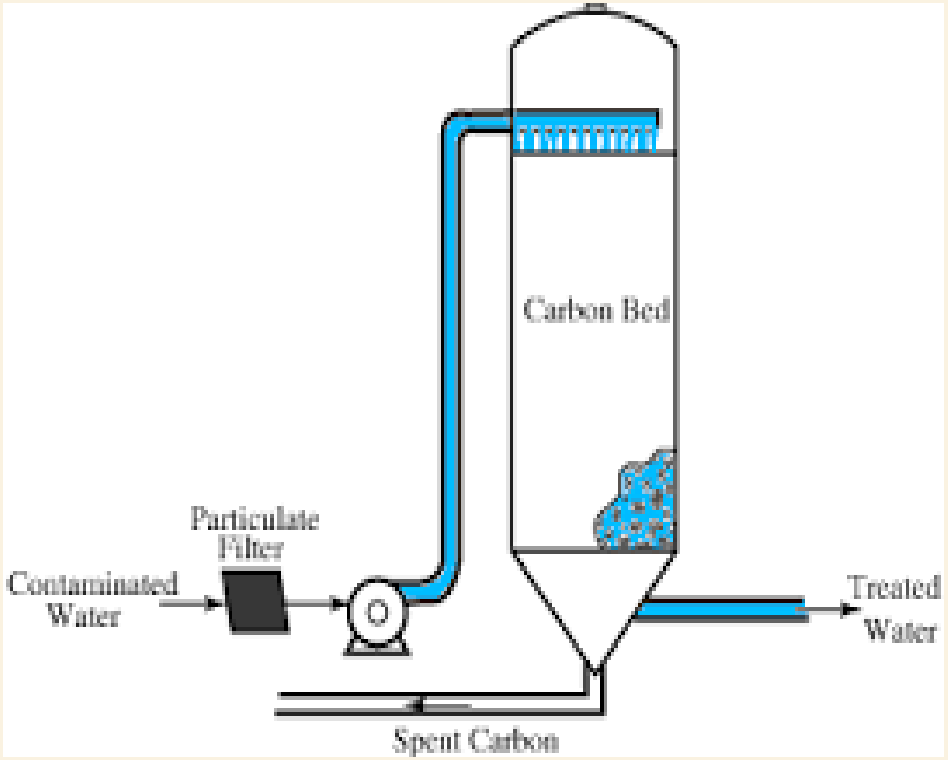
- Pore size
- Total surface area
- Chemical nature of the carbon surface (example, acidic or basic)



ACTIVATED CARBON TREATMENT OF DRINKING WATER

Substances removed include

- Chlorine and chlorinated hydrocarbons
- Phenols and related compounds
- Many other organic compounds, such as dyes and surfactants
- Some inorganic ions



COAL IN AGRICULTURE

The possible uses of coal in agriculture include:

- Hydroponics
- Soil amendment
- Fertilizer

HYDROPONICS

Hydroponics—way of growing plants without soil.

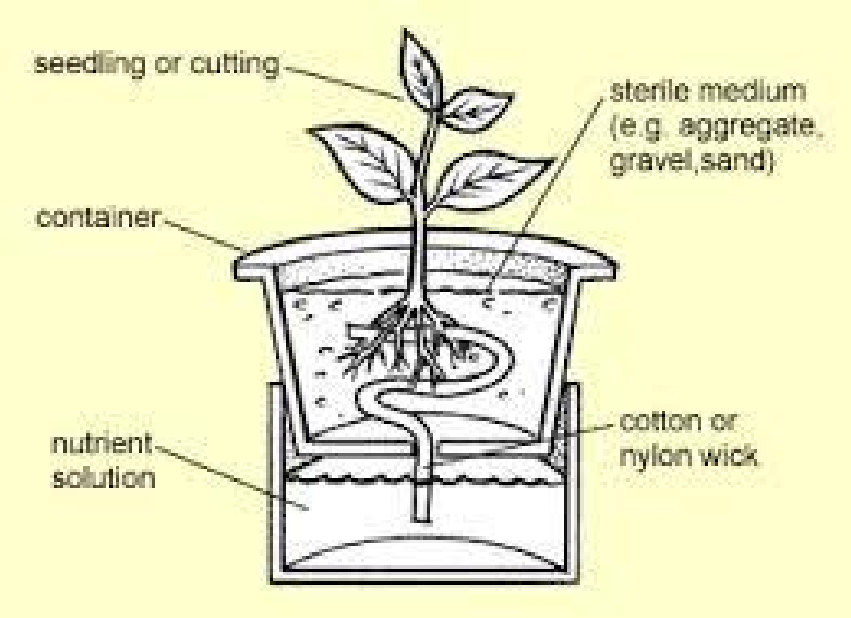
Hydroponics involves growing plants in water. Plant nutrients are added to the water.

The plant roots are usually held in a solid, called the substrate.

Recent research in the U.S.A. has shown that anthracite can be a very good substrate for some kinds of food plants.

EXAMPLES OF FOOD PLANTS GROWN WITH HYDROPONICS

HYDROPONIC SUBSTRATES



Substrate holds the plant roots.

Water, or plant nutrients in water, flows around the substrate particles.

Crushed anthracite works well as a substrate for food crops such as tomatoes, lettuce, or radishes.

FERTILIZERS FROM COAL

Humic acids—complex high molecular weight organic acids. Soluble in solutions of bases (example: NaOH), but precipitated by adding acid.

Humic acids in soil help plant growth by retaining water and nutrients, giving the water or nutrients to the plant roots.

Humic acids can be extracted from low-rank coals (examples lignite and brown coals) by using water solutions of NaOH or KOH.

ESSENTIAL PLANT NUTRIENTS

Many elements are important for plant growth.

The three most important elements are

- Nitrogen
- Potassium
- Phosphorus

How can we increase the amount of nutrients in humic acids made from lignite?

POTASSIUM AND NITROGEN

Extract humic acids using water solution of KOH.

$$KOH + Lignite \longrightarrow K^{+} Humate^{-}$$

Removal of the water gives solid potassium humate.

Add acid to the humic solution in KOH.

Recover humic acids.

React with HNO_3:

$$Humic\ acid + HNO_3 \longrightarrow Humic\text{–}NO_2$$

EXAMPLE 2.

STEEL

EVERY PERSON DEPENDS ON STEEL

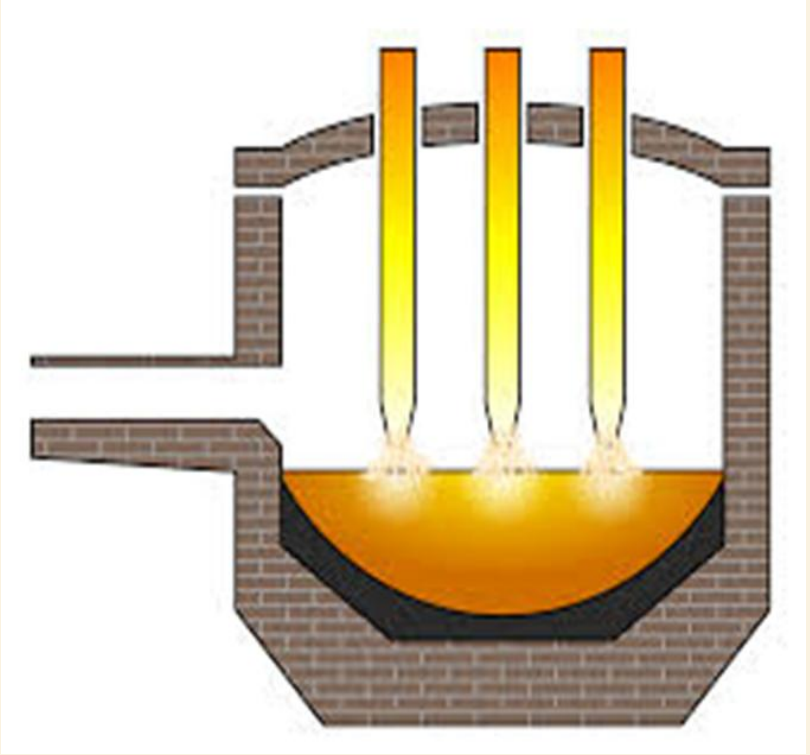
Steel is our most important metal. Examples of uses: buildings, automobiles, ships, railways, tools, machines, home appliances…and more…

World steel production in 2017 was 1,700 million tonnes.

Today China produces 50% of world steel. Steel has been made in China for ≈1000 years (Song dynasty).

ARC FURNACES IN THE STEEL INDUSTRY

About 60% of domestic steel production comes from re-melting scrap steel in arc furnaces.



MEDIUM-SIZE ARC FURNACE

A capacity of about 100 tonnes (100,000 kg) of scrap steel.

Capable of melting 100 tonnes of steel in an hour.

Very big consumption of electricity–40 MW. (Like a city of ≈90,000 people!)

ELECTRODE REQUIREMENTS

A graphite electrode must

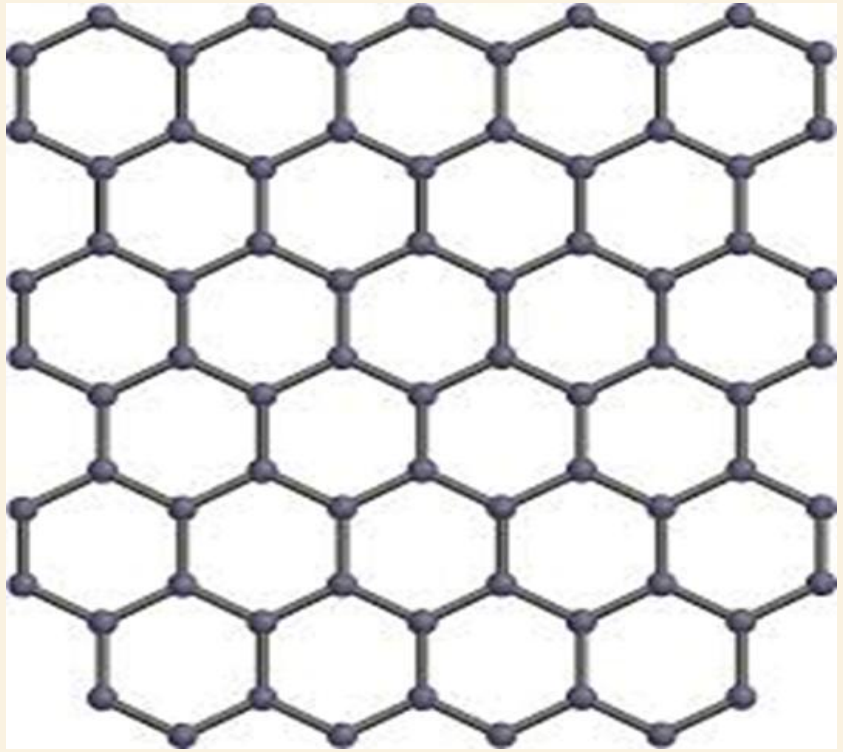
- Support its own weight (several tonnes)
- ΔT from white hot to near-ambient over ≈ 4 m
- Appropriate electrical properties
- Resist catching on fire
- Avoid thermal expansion

STRUCTURE OF GRAPHITE. 1.

100% carbon. All atoms are in aromatic ring systems making an infinite planar hexagonal array.

One hexagonal plane is called a *graphene* sheet.

A crystal of graphite is an ordered, regular stack of graphene sheets.



STRUCTURE OF GRAPHITE. 2.

A stack of cards is a good model for the ordered, regular stack of graphene sheets.

The cards model explains the anisotropic physical properties. It is very hard to tear the stack across, but very easy to “smear” out the deck.

HOW GRAPHITE ELECTRODES ARE MADE

Mix a carbonaceous solid (example petroleum coke) with coal-tar pitch.

Press the mixture into desired size electrode.

Graphitize at ≈2700–3000° C.

MAKING GRAPHITE FROM COAL

To produce material that is 100% carbon, it is good to start with coal that is ≥90% carbon.

Such coals are anthracites.

Anthracites also contain small percentages of H, N, O, and S.

These other elements have effects on the anthracite structure.

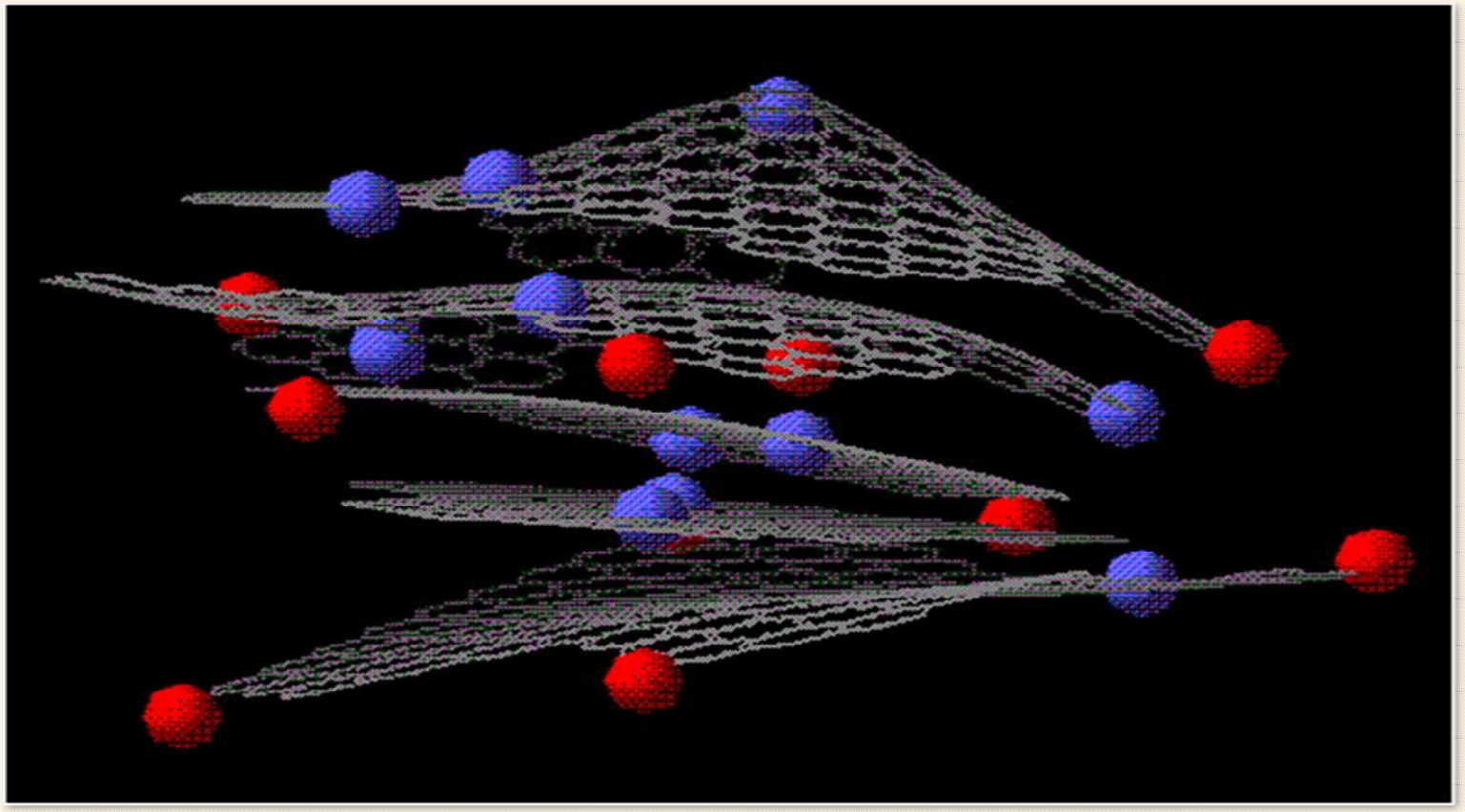
PRINGLE MODEL FOR ANTHRACITE STRUCTURE

O, N, or S atoms distort the planar graphene stacks found in graphite.

5- (also 7- ??) carbon atom rings occur in the structure. These also distort the graphene stacks.

The distortions are not uniform from layer to layer. This makes 3-dimensional stacking difficult.

COMPUTER-GENERATED STRUCTURAL MODEL OF ANTHRACITE



CHANGING ANTHRACITE TO GRAPHITE

To convert anthracite to graphite,

- Remove H, S, N, and O
- Change aliphatic carbon to aromatic
- Rearrange 5- or 7-carbon atom rings to 6
- Flatten curved sheets into planar graphene layers.

How to do this?

- Many reactions can happen at ≈3000° C. Graphite is the thermodynamically stable form of carbon.
- Possible *in situ* catalysis by minerals in the anthracite.

IN SITU CATALYSIS OF ANTHRACITE GRAPHITIZATION

Quartz grains in anthracite are surrounded by carbon.

At temperatures ≈1600° C

$$SiO_2 + 2\ C \rightarrow SiC + CO_2.$$

Quartz will react first with less stable (disordered) carbon.

At temperatures >2400°

$$SiC \rightarrow Si + C.$$

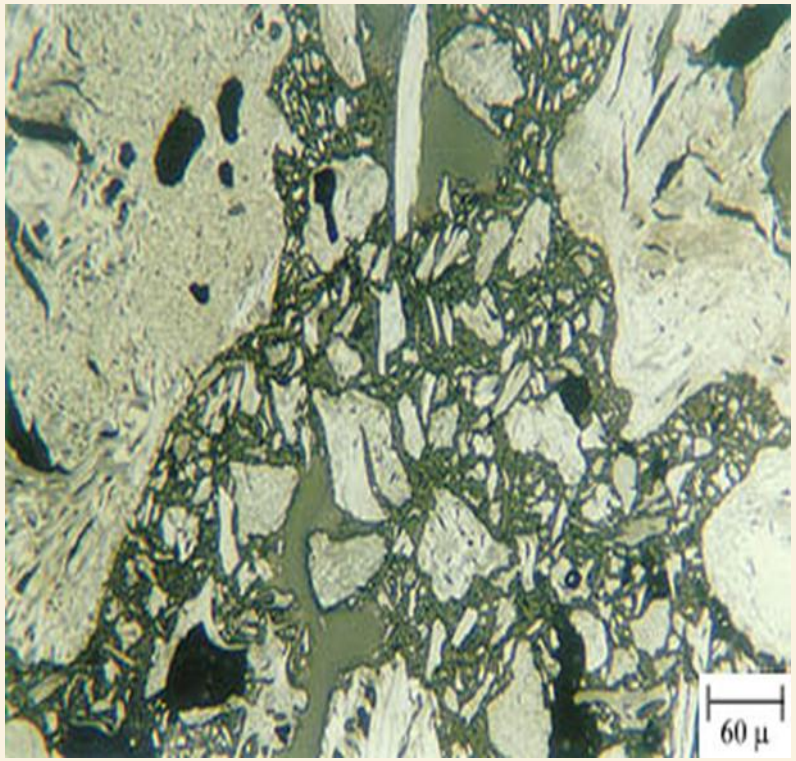
Carbon forms as graphite—its thermodynamically stable state.

MAKING GRAPHITE FROM ANTHRACITE

Comparing industrial graphites made from petroleum coke (the standard way) and from anthracite under identical conditions.

	Control sample	*Graphitized anthracite*
Interlayer spacing, nm	0.3349	0.3354
Stacking heights, nm	30.2	29.1
Resistivity, μΩ·m	0.00046	0.00046
Flex strength, MPa	40.8	42.6
Density, g/cm^3	1.74	1.70
Hardness, Rockwell scale	76	97

UNINTENDED CONSEQUENCES



Graphite electrodes are made from two components: petroleum coke and coal tar pitch.

But—coal tar pitch is a by-product of the metallurgical coke industry.

Increased use in graphite electrodes to make steel reduces coke demand. This reduces the availability of coal tar pitch.

CHALLENGES

SOME RESEARCH PROBLEMS ON MATERIALS AND CHEMICALS FROM COAL

COAL TAR PITCH

Coal tar pitch is needed to make graphite electrodes. Pitch comes from by-product coke ovens. The more graphite we use, the less coke we need to make. Reduced coke production means reduced supply of coal tar pitch. Is there a way to make coal tar pitch without a coke oven?

- Mild hydrogenation of anthracite?
- Using by-product tar from fixed bed gasifiers?
- Or your ideas??

NEW WAYS TO MAKE ACTIVATED CARBONS

Activation of coals involves high-temperature reactions, or corrosive chemicals. Is there an easier way to make activated carbon from coal?

- Use of new reaction methods: ultrasound, electron beams, photochemistry?
- New chemical reactions for selective removal of surface carbon atoms.
- Or your ideas??

MAKING CHEMICALS FROM COAL

For 75 years (≈1875-1950) the world's organic chemical industry was based on chemicals from coal tar. Can we develop new ways of making chemicals from coal without coal tar?

- Selective bond-breaking in coal?
- New chemical reactions or new catalysts?
- Or your ideas??

THANK YOU!

A FEW USEFUL REFERENCES

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