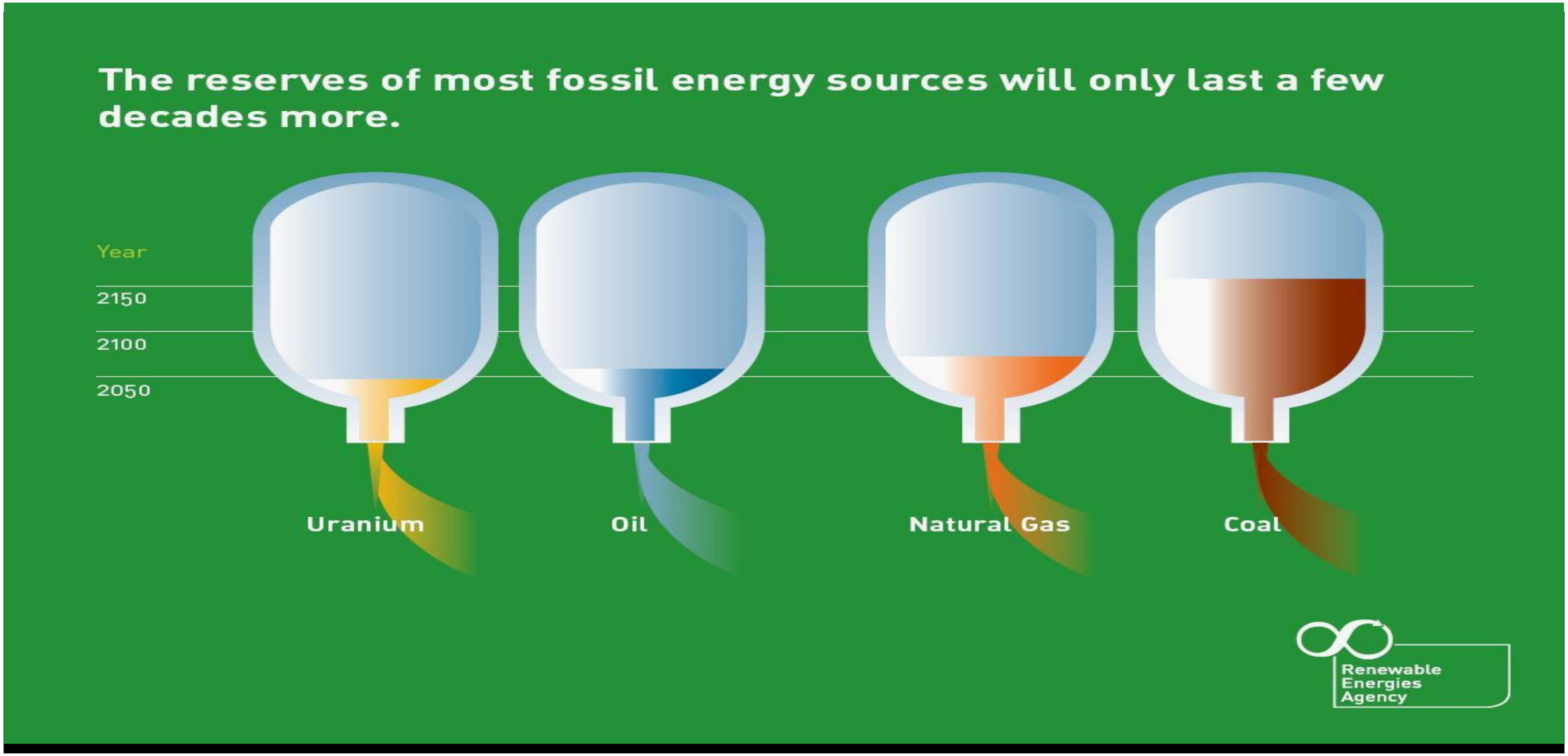
Unit III- Clean Coal Technologies

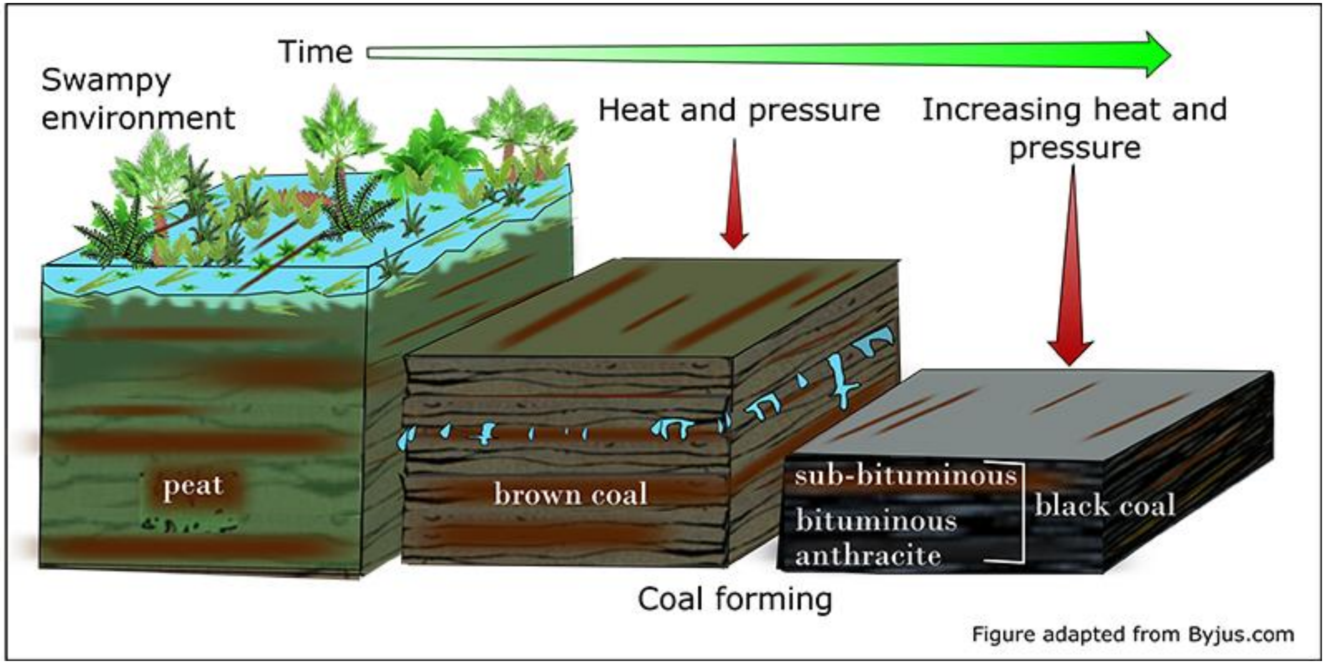
Energy supply

- Till now most of the global energy demand is fulfilled by oil & coal

Forecast of Global Energy resource reserves

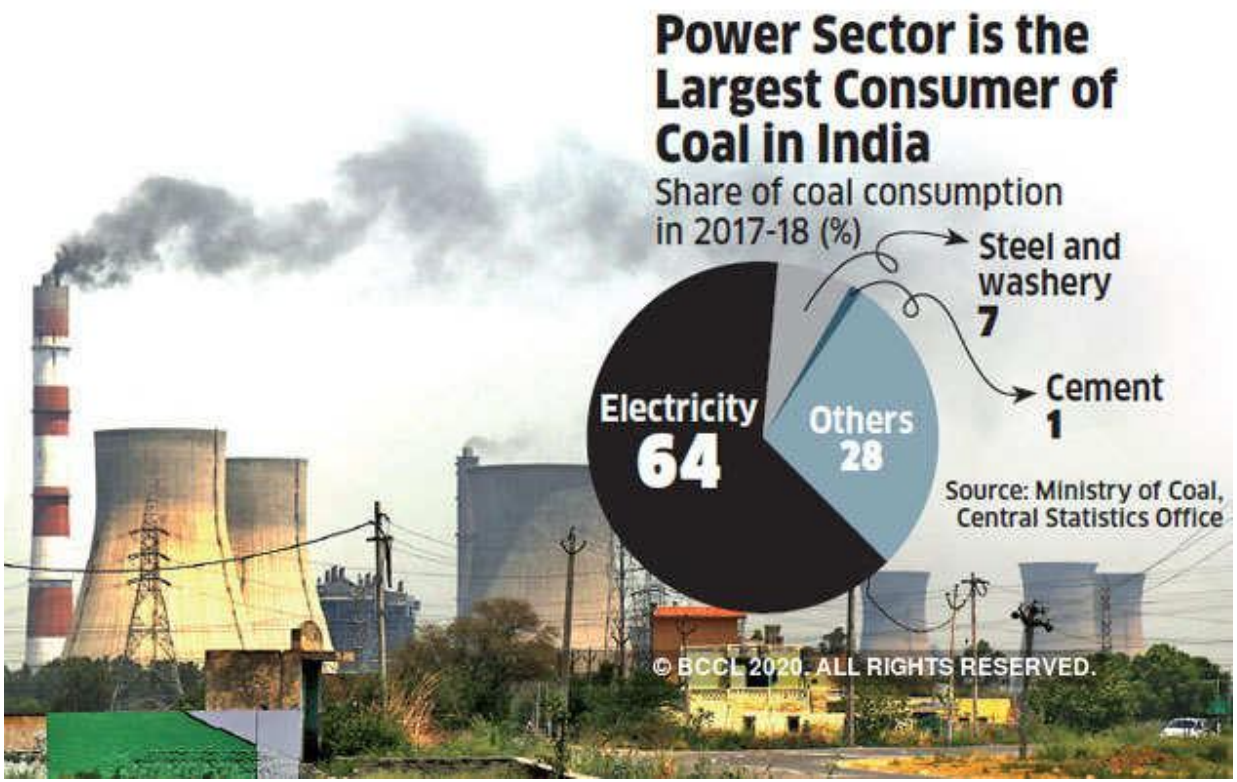


Formation and types of Coal

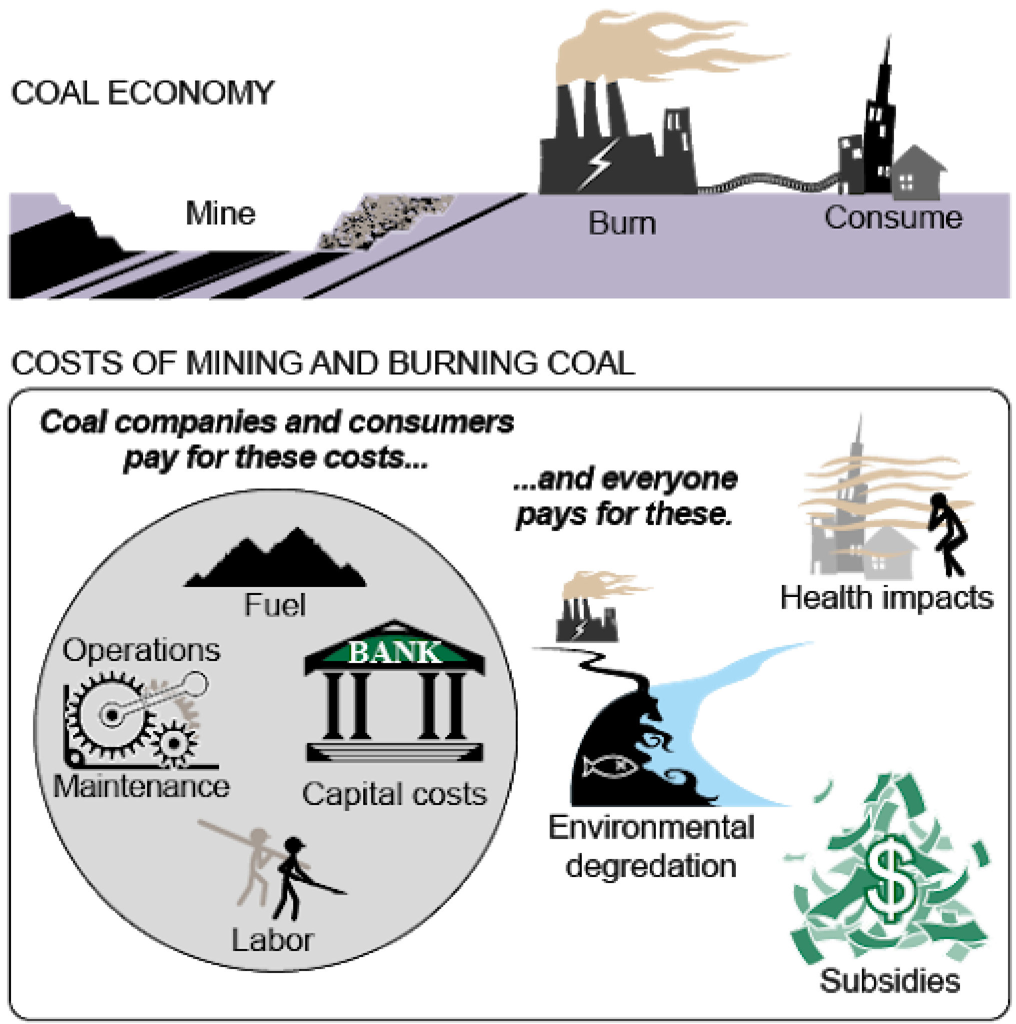


- Lignite (brown coal) - 25% to 35% carbon, around 70% when dry
- Subbituminous – 35% to 45% carbon
- Bituminous – 45% to 86% carbon
- Anthracite (black coal) – 86% to 98% carbon

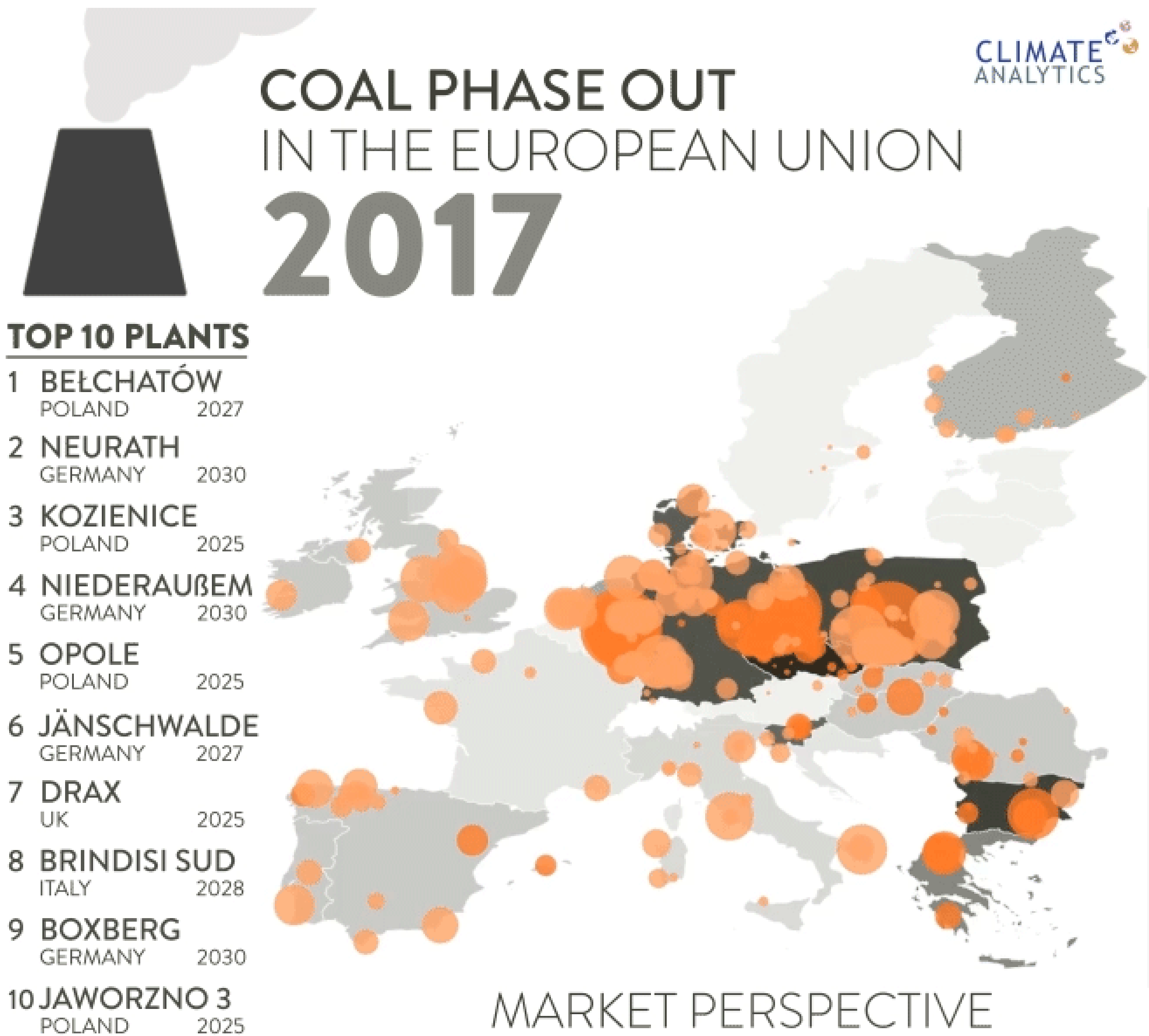
Coal and Electricity



Negative impacts of coal



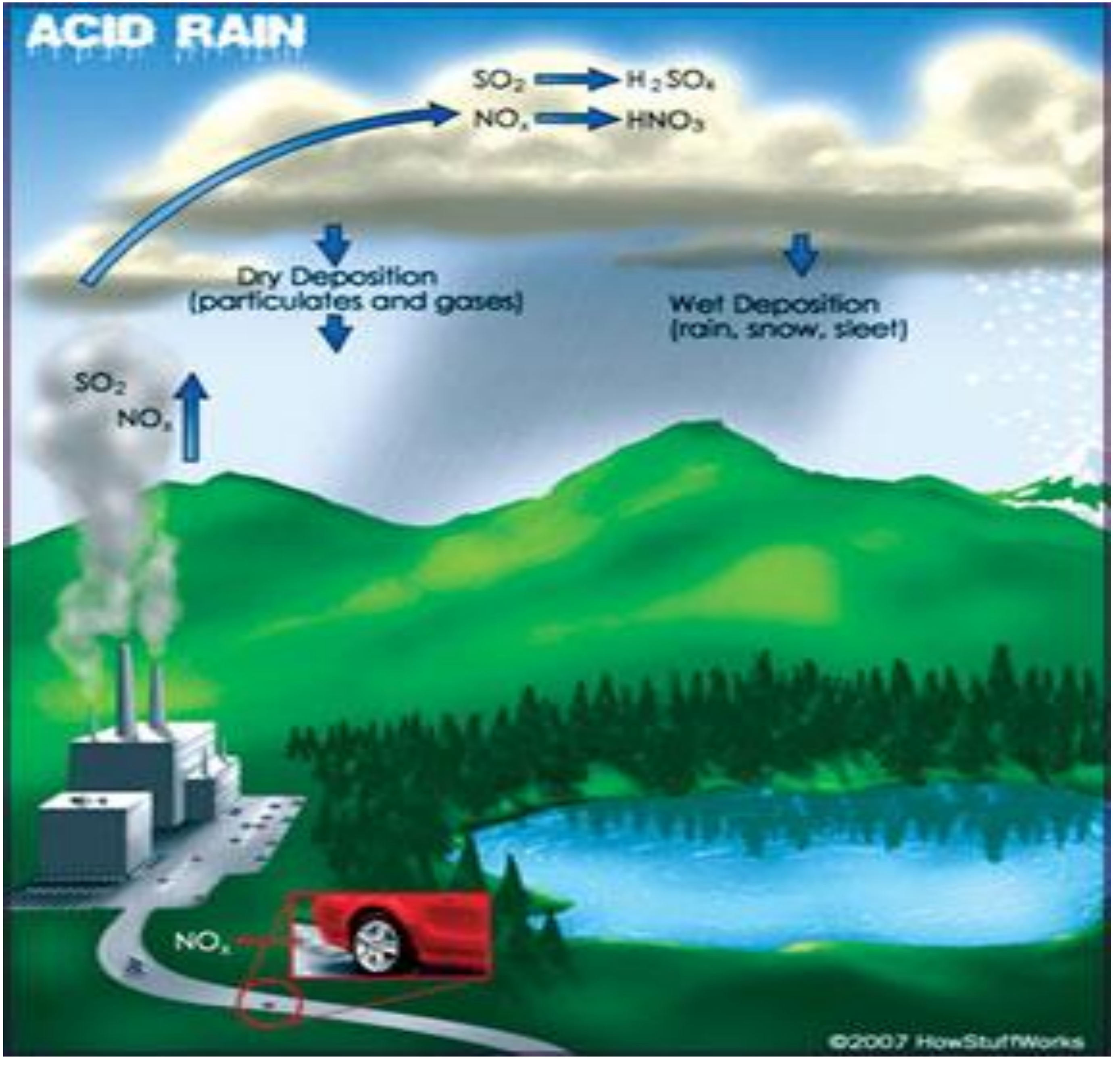
Coal Phase out in Developed countries



Burning of Coal

- In 2002 fossil fuels released 23 billion tons of CO2 into the atmosphere of the 23 billion tons 41% was from coal
- Burn 1 ton of black coal and you get 4 tons of CO2
- Anthracite releases 67% more CO2 than methane and brown coal releases 130% more CO2 emissions than methane
- Coal also contains trace amounts of sulfur and Nitrogen that when burned can cause environmental issues

Effect of Air pollution



Effect of acid rain in Germany

200 year old statue

1908 1968

Limitations of conventional lignite (a form of coal) processing

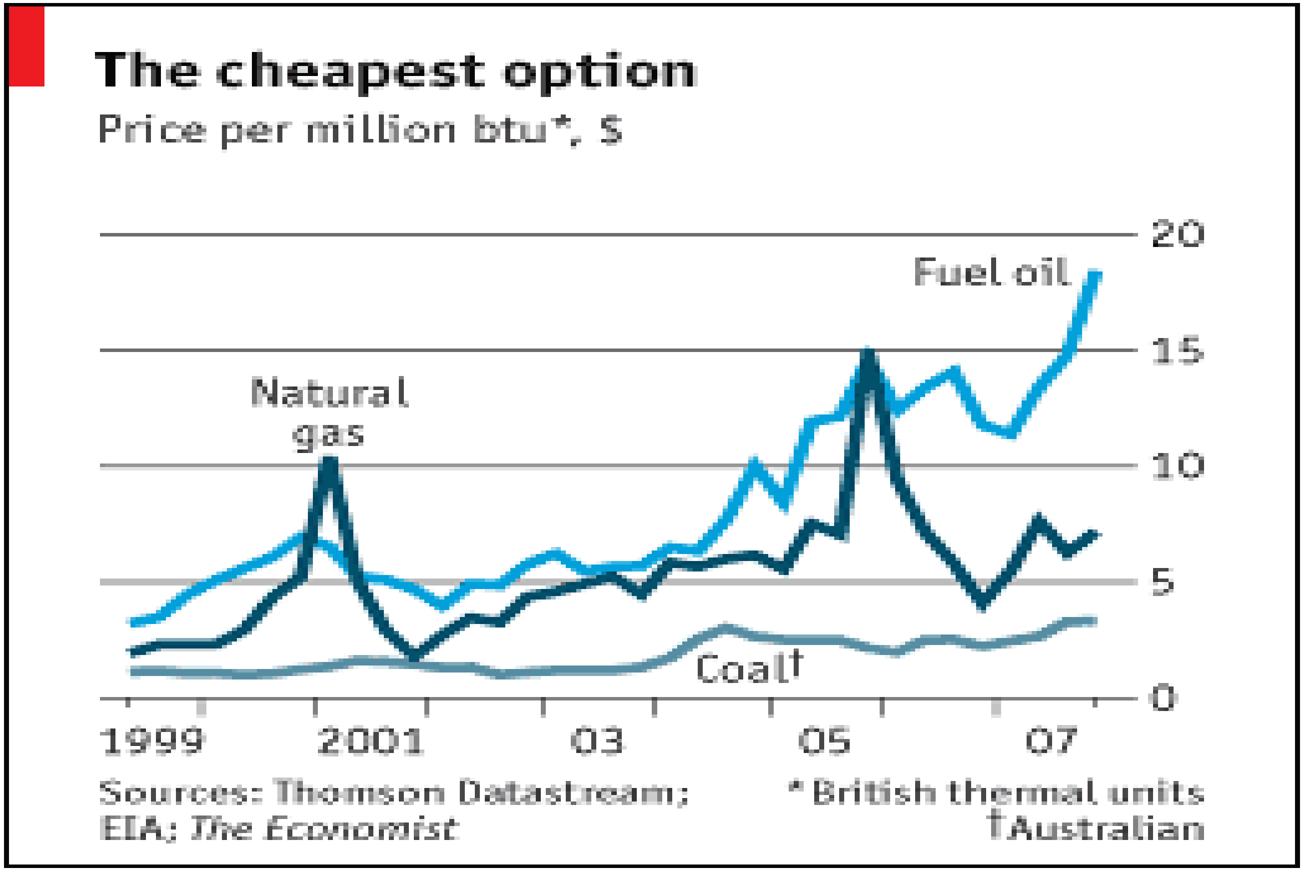
1. Conventional lignite processes are not cost effective , due to its low calorific value and presence of contaminants in considerable amount when compared to other coal forms

2. Government regulations prevent burning of the majority of these coals because of their high sulfur content & their impact on environment pollution

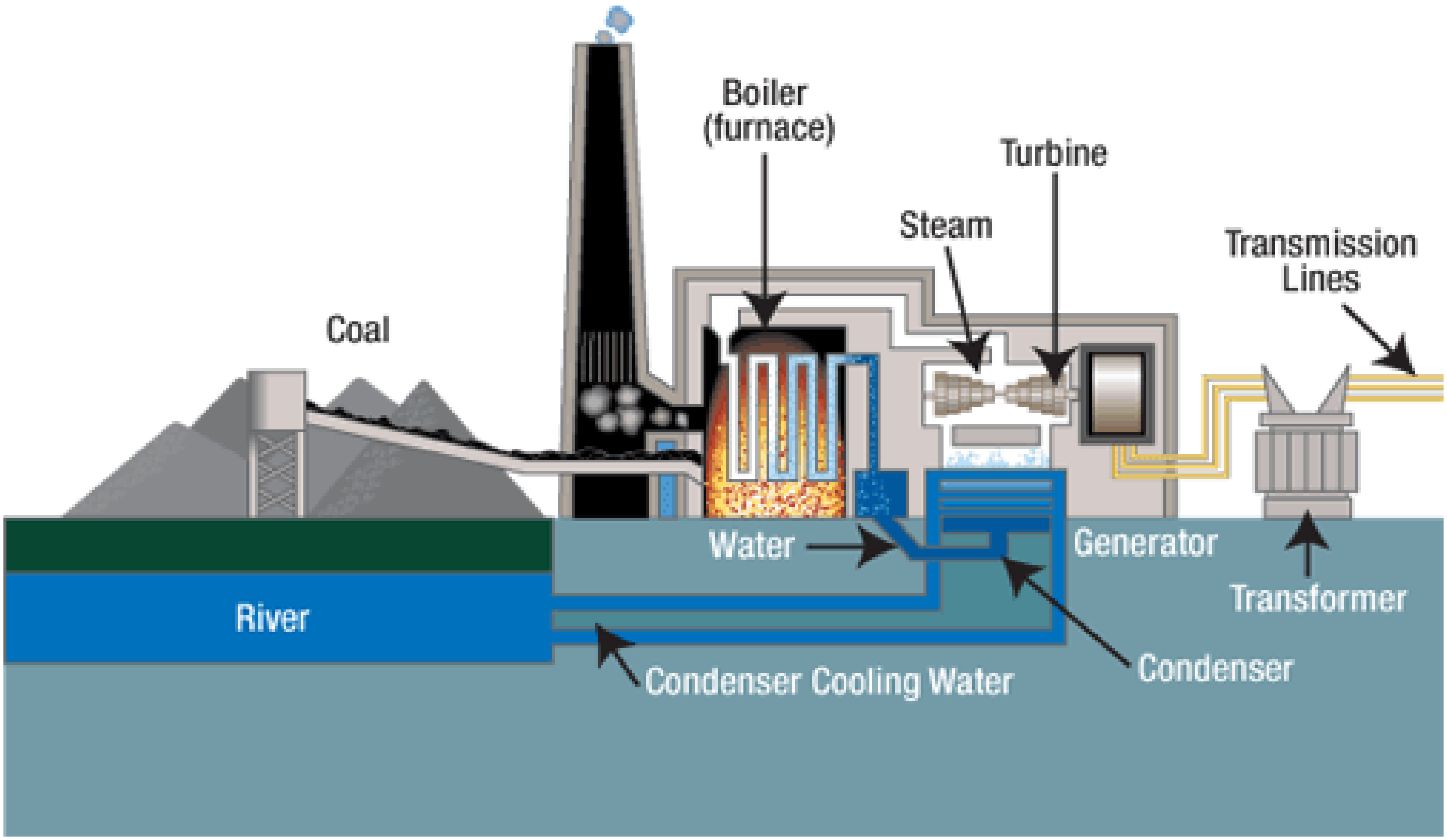
- For these reasons there is a need for exploring uses of lignite other than conventional combustion & to make lignite the feedstock for production of clean fuel or other beneficial non fuel

Why is coal still used?

- Cheapest for power stations relative to the amount of heat it generates when burnt



How does a coal power plant work?



So what is clean coal?

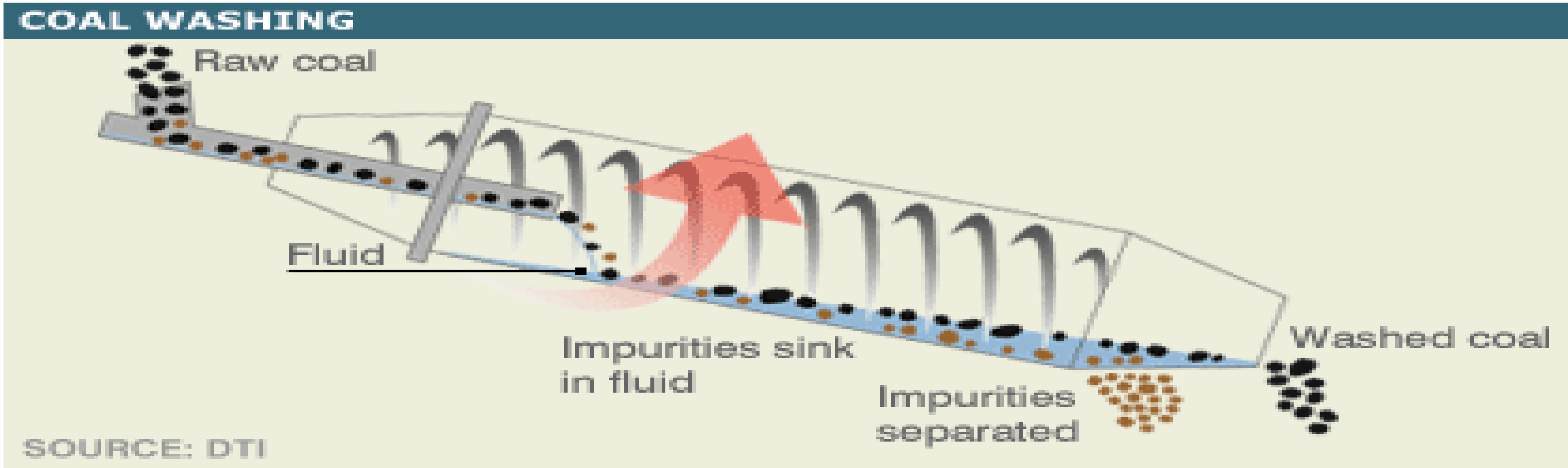
- It is actually a vague term that does not describe any one process
- Can include the removal of nitrogen and sulfur that create acid rain
- Can include the storage of CO_2
- The term “clean coal” is abused

“Clean” Coal Technologies

- Coal washing
- Wet scrubbers
- Electrostatic precipitators
- Gasification
- Carbon Capture and Storage (CCS)
- Fuel Cells
- Magnetohydrodynamics

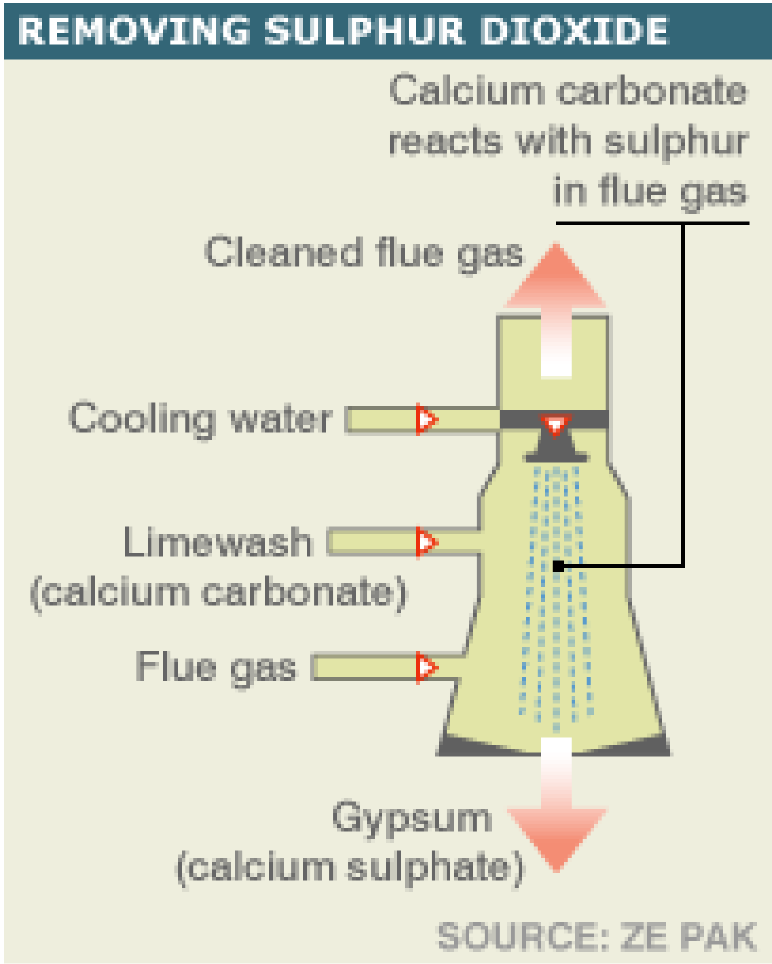
Coal Washing

- Grinding coal into pieces and passing it through gravity filtration
- One technique: Putting coal into a barrel with a liquid with a specific density where the coal floats and the impurities sink



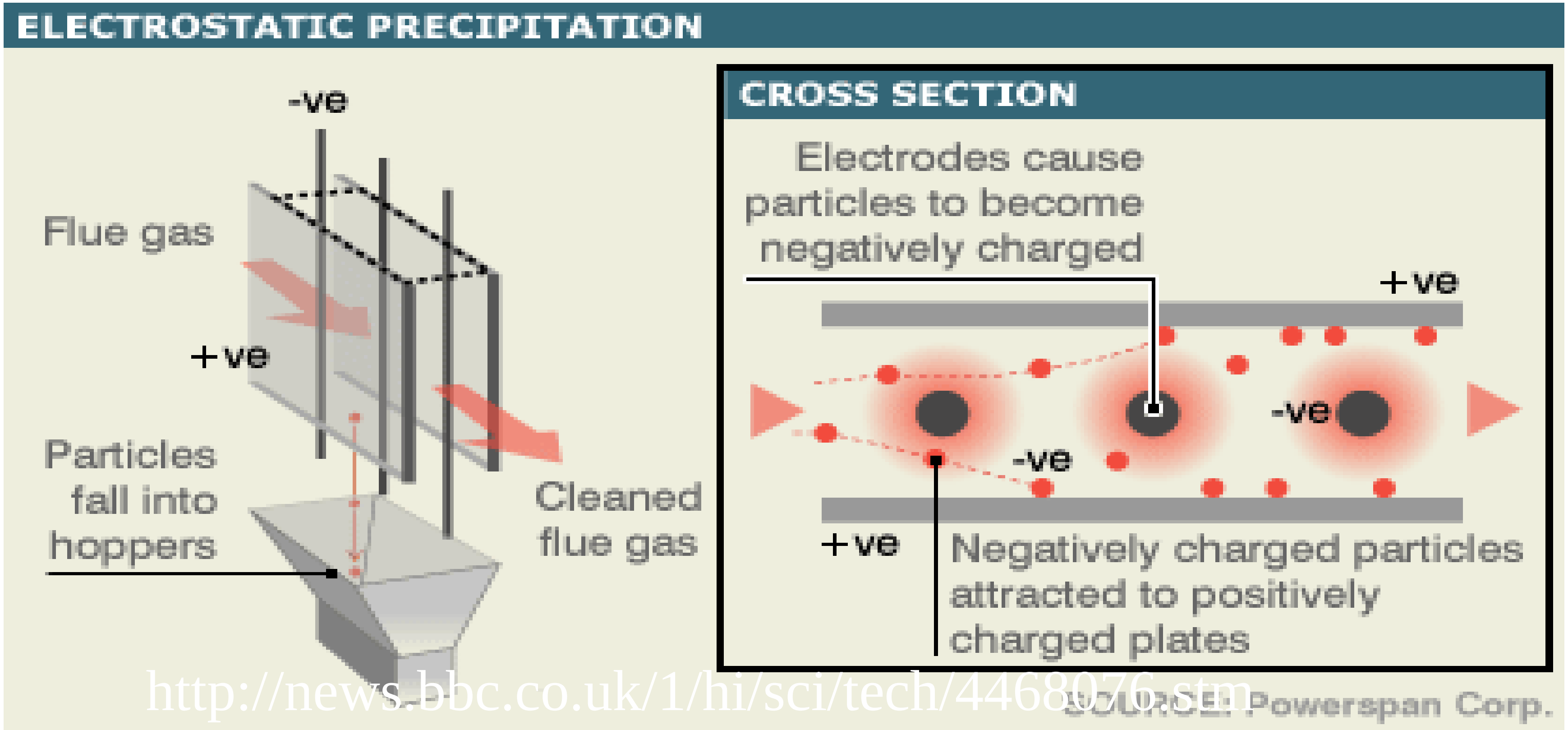
Wet Scrubbers

- When the emissions reach the flue of the furnace limestone and water are sprayed
- The SO2 reacts with the calcium carbonate (limestone) to form gypsum (calcium sulfate)
- The gypsum is collected and used for construction
- 99% effective



Electrostatic Precipitators (Particle emissions)

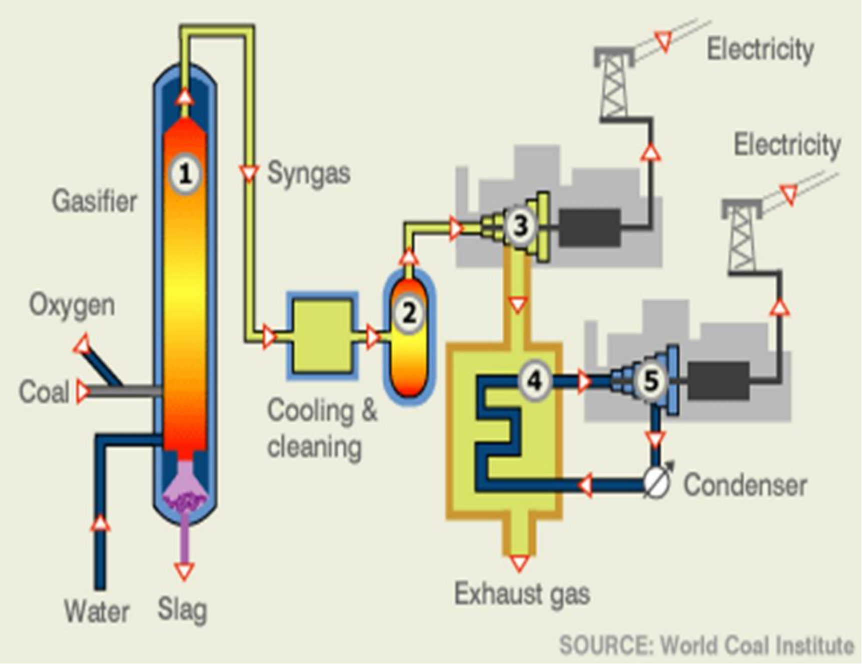
- Creates an electrical field that removes unwanted charged particles
- 99% effective



http://news.bbc.co.uk/1/hi/sci/tech/4468076.stm

Gasification

- Coal is reacted with oxygen and steam to form a “syngas” (mostly hydrogen and part CO)
- Syngas is cleaned and burned which then turns a turbine
- As gas cools it heats water, which turns another turbine

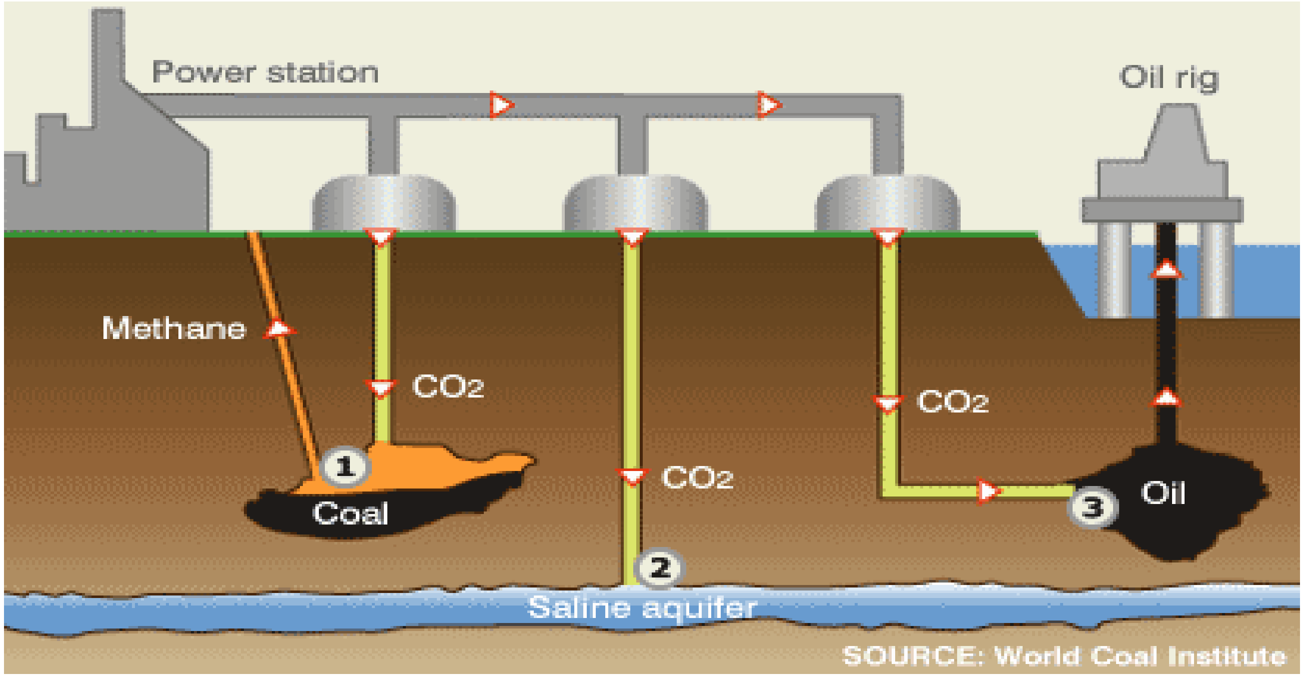


Gasification (continued)

- Gasification is seen as part of zero-emission system
- Improved SO2 and NOx emissions (already low)
- Unproven on widespread scale
- Up to 45% efficient
- Currently only demonstration units exist on a trial basis
- Right now syngas being cleaned at low temperatures. In the future will be cleaned at higher temperatures, increasing efficiency
- Costly, but current coal power plants can be modified

Carbon Capture and Storage (CCS)

- Capturing CO_2 and storing it underground (geosequestration)

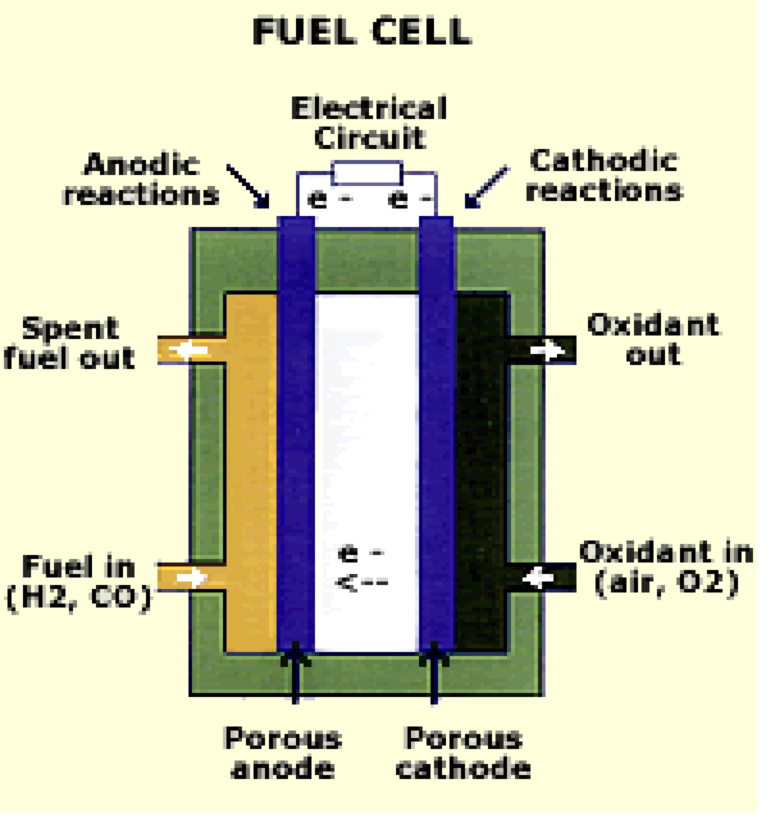


CSS (continued)

- There are many problems with CSS
- CO_2 is hard to capture
- Once captured it needs to liquefied which takes 20% of the energy yielded from the coal
- Where the CO_2 is stored needs to be monitored
- There are only so many places that are good for mass storage
- Transportation could be costly

Fuel Cells

- Allow hydrogen from coal to react with oxygen to produce electricity electrochemically
- Still in early development
- Costly



Magnetohydrodynamics

- Coal is burned to form an extremely hot gas or plasma
- Given electrical charge by adding a compound like potassium salt
- The charged gas or plasma is passed through a magnetic field and electricity is produced
- The heat from the combustion gases is used to turn a steam turbine too
- Still in development
- Costly

So is “clean” coal really clean?

- Unfortunately there is no way to make coal clean
- Processes like gasification can make coal burning more efficient, but it still burns plenty of CO_2
- CO_2 can be stored underground using CSS, but that could lead to more problems in the future
- Best solution: STOP USING COAL??!!! No Still There is a way

Rationale for biological processing of lignite

- Biological origin
- Structural similarity with lignin
- Structural components of lignite which could be amenable to microbial action
- Availability of certain sites in the structure which could be targets for microbial mediator action
- Biological processing can be carried out at ambient temperatures and conditions
- Possibility of modulation and control of the conversion process for obtaining specific target products

Biodepolymerization of low grade lignite to humic acid and biomethane

Applications of lignite bioconversion

- **Conversion to combustible liquid**

  - Transportation and technical handling possible
  - A support for recultivation of open cast mining areas

- **Conversion to small macromolecules**

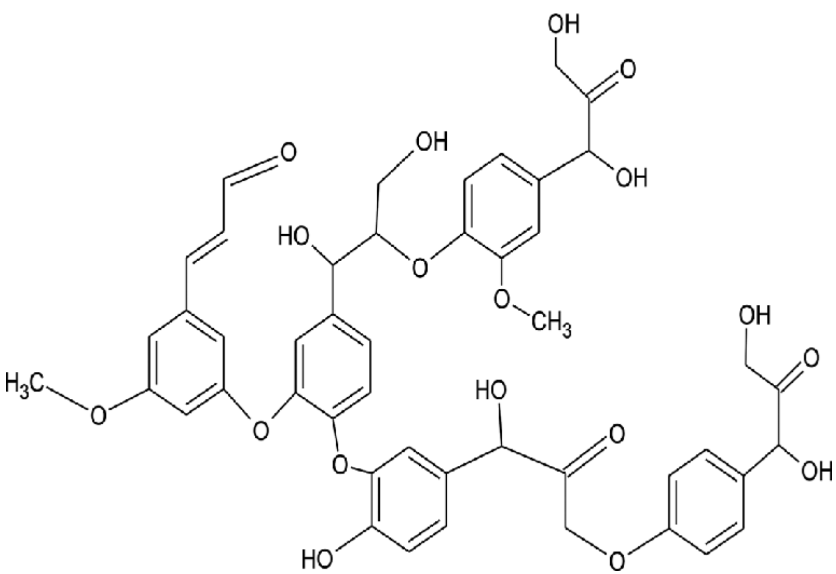
  - Fuel benefit
  - Production of value added materials
  - Fertilizers, ion exchange materials like Humic acid and Fulvic acid
  - Further conversion to bioplastics

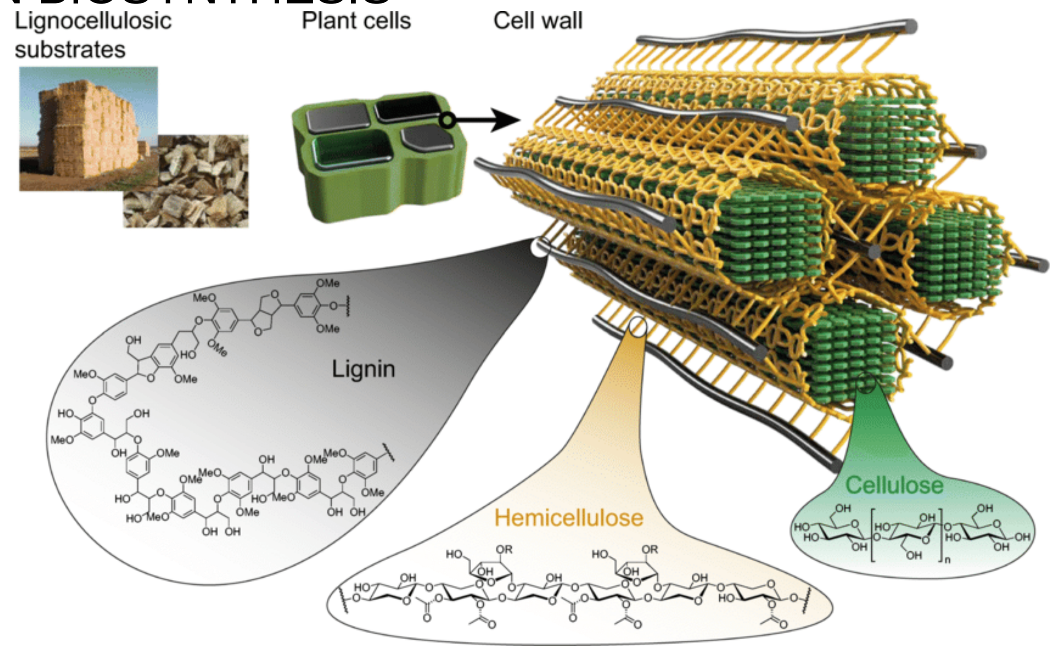
- **Conversion to methane**
  - Clean fuel
  - No ash problems

Summary

- Coal is very inefficient and is a huge cause of global warming, but cheap
- Clean coal is a term that describes many different technologies
- Clean coal is by no means clean
- CSS will be put in use in the near future, which may or may not be a good thing

LIGNIN BIOSYNTHESIS





Lignin is a polymer that serves as a matrix around the polysaccharide components of some plant cell walls, providing additional rigidity and compressive strength as well as rendering the walls hydrophobic and water impermeable.

Terrestrial vascular plants may therefore have appeared only after the evolution of lignin biosynthesis, because structural support and water transport functions are central to the biology of higher land plan.

Lignin biosynthesis is a very complex network that is divided into three processes: (i) biosynthesis of lignin monomers, (ii) transport and (iii) polymerization

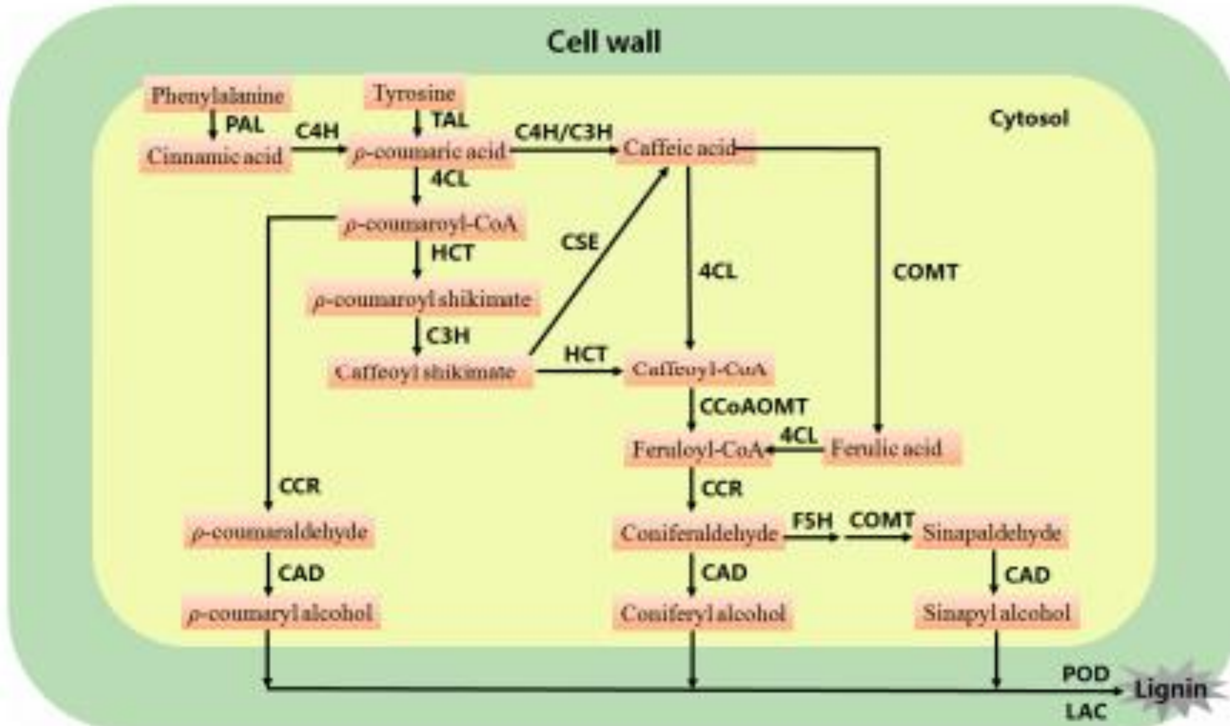


Figure 1. The general biosynthesis pathway of lignin in higher plants. PAL, phenylalanine ammonia-lyase; TAL, tyrosine ammonia-lyase; C4H, cinnamate 4-hydroxylase; 4CL, 4-coumarate: CoA ligase; CCR, cinnamoyl-CoA reductase; HCT, hydroxycinnamoyl-CoA shikimate/Quinatehydroxycinnamoyltransferase; C3H, *p*-coumarate 3-hydroxylase; CCoAOMT, caffeoyl-CoA *O*-methyltransferase; F5H, ferulate 5-hydroxylase; CSE, caffeoyl shikimate esterase; COMT, caffeic acid *O*-methyltransferase; CAD, cinnamyl alcohol dehydrogenase; LAC, laccase; POD, peroxidase.

Role of Lignin in Plant Drought and Salt Stress Tolerance:

Extreme drought and high salt stress usually occur simultaneously and induce osmotic stress that causes plant cells to lose water or even die, significantly affecting plant growth and development and resulting in serious losses of crop yield. Lignin can reduce plant cell wall water penetration and transpiration, which helps to maintain cell osmotic balance and protective membrane integrity.

Role of Lignin in Plant Temperature Stress Adaptability:

Climate change affects the temperature of plant growth environment, high temperature induces the damage of biomacromolecules such as protein and nucleic acid, exacerbates membrane lipid peroxidation and disturbs the normal plant metabolism. In contrast, low temperature stress also causes cell membrane damage, reduces plant photosynthesis and respiration and severely inhibits plant growth and development.

Role of Lignin Deposition in Plant Heavy Metal Tolerance:

As the first entry barrier for metal ion, cell wall is actively involved in the absorption and transport of heavy metals and the plant response to heavy metal stress. Heavy metals stress can stimulate phenolic secondary metabolic synthesis pathway and increase the lignin content in secondary cell wall, thereby enhance the thickness of the cell wall. As lignin polymer contains a large number of functional groups (hydroxyl, carboxyl, methoxyl, etc.), it can bind multiple heavy metal ions (Cu^{2+}, Cd^{2+}, Pb^{2+} , etc.) and reduce the entry of heavy metals into the cytoplasm.

Roles of Lignin Biosynthesis in Plant Insect Pests and Diseases

Resistance Lignin accumulation plays an important role in the process of plant resistance to insect pests. Rice PAL, C4H and pathogenesis-related 9 (PR9) genes that associated with lignin biosynthesis were significantly up-regulated in brown plant hopper-infested insect-resistant rice varieties, suggesting that these may synergistically participate in lignin biosynthesis which regulate the insect resistance of rice.

Role of Lignin in Plant Growth and Development:

As one of the main components of the plant cell wall, lignin confers to the function of multiple types of cells in plants tissues and organs. Lignin metabolism is involved in plant growth and development, interference of lignin biosynthesis, especially H units, often leading to inhibition of plant growth and deformity development . In some plants, lignin accumulation is important for the seed propagation . The deposition of lignin in seed coat can protect the seeds from external adverse factors

Genetic engineering for bioenergy

What is hybrid?

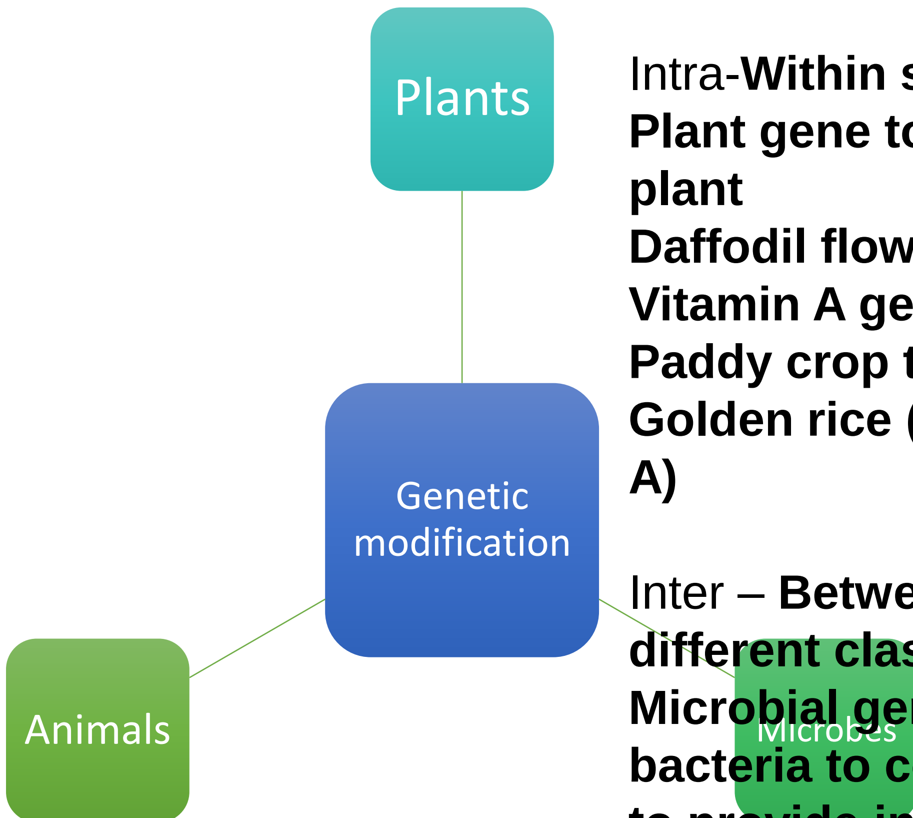
A car that runs on petrol and also on CNG is hybrid system

A tab that can be convertible as laptop is a hybrid system

In biology, a hybrid is the offspring resulting from combining the qualities of two organisms of different breeds, varieties, species or genera through sexual reproduction or by genetic engineering

Potamato: Potato and tomato in a single plant

Genetic Modification (GM)



Intra-**Within same class Plant gene to another plant**
Daffodil flower – Vitamin A gene to Paddy crop to get Golden rice (Rich in Vit A)

Inter – **Between two different class Microbial gene from bacteria to cotton plant to provide insect resistence resistance**

Advantages of GM crops

- **Contributing to food security and more available food (lower prices)**

  - Biotech crops can play an important role by contributing to food security and more available food through an increasing of productivity per hectare and a decreasing cost of production by a reduced need for inputs, less ploughing and fewer pesticide applications, which in turn also requires less fossil fuels for tractors, thus mitigating some of the negative aspects associated with climate change

- **Contributing to sustainable economic benefits**

  - It is estimated that the global net economic benefits to biotech (GM) crop farmers in 2007 alone was $10 billion ($6 billion for developing countries and $4 billion for industrial countries).

Advantages of GM crops

- **Conserving biodiversity**

- Biotech crops are a land-saving technology, capable of higher productivity on the current 1.5 billion hectares of arable land, and thereby can help prevent deforestation and protect biodiversity in forests and in other in-situ biodiversity places

- **Contributing to the alleviation of poverty and hunger**

- The 50% of the world's poorest people are small and resource-poor farmers, and another 20% are the rural landless completely dependent on agriculture for their livelihoods. Thus, increasing income of small and resource-poor farmers contributes directly to the poverty alleviation of a large majority, around the 70% of poorest people in the world.

Advantages of GM crops

- **Reducing agriculture's environmental footprint**

- The utilization of GMO implies a reduction in pesticides, saving on fossil fuels, and decreasing CO_2 emissions through less ploughing, and conserving soil and moisture by optimizing the practice of no till through application of herbicide tolerance. Also, the efficiency of water usage and availability of water globally increased. Seventy percent of fresh water is currently used by agriculture globally, and this is obviously not sustainable in the future as the population increases by almost 50% to 9.2 billion by 2050.

- Another expectative is that the drought tolerance has a major impact on more sustainable cropping systems worldwide, particularly in developing countries where drought is more prevalent and severe than industrial countries.

Advantages of GM crops

- **Mitigating climate change and reducing greenhouse gases (GHG)**

- The most important contribution of GMO crops in the environmental is the reduction of greenhouse gases and help mitigate climate change in two ways.

- The first one is saving in carbon dioxide emissions through reduced use of fossil-based fuels, associated with fewer insecticide and herbicide sprays.
- Secondly, additional saving from conservation tillage (need for less or no ploughing facilitated by herbicide tolerant biotech crops) for biotech food, feed and fibre crops, led to an additional soil carbon sequestration.

Advantages of GM crops

- **Contributing to the cost-effective production of biofuels**

- Biotechnology can be used to cost-effectively optimize the productivity of biomass/hectare of first generation food/feed and fiber crops and also second-generation energy crops. This can be achieved by developing crops tolerant to abiotic stresses (drought/salinity/extreme temperatures) and biotic stresses (pests, weeds, diseases), and also to raise the ceiling of potential yield per hectare through modifying plant metabolism

- There is also an opportunity to utilize biotechnology to develop more effective enzymes for the downstream processing of biofuels. In the USA, Ceres has just released biotech-based non-transgenic hybrids of switchgrass and sorghum with increased cellulose content for ethanol production and has transgenic varieties under development.

GM biofuel crops

GMO

- Generally GMOs are modified organisms, which modification is done by insertion or deletion of genes (pieces of DNA). In nature such kind of modification is happening but very slowly and almost unnoticeable. NCALRI (2000) defined regarding the GMO in which "the genetic make up of organisms and producing unique individuals or traits that are not easily obtained through conventional breeding techniques".

GMO plants for biofuel

- For getting biofuels from plants numerous processes have to be complete. For instance, crops, bacteria, yeasts, catalysts etc. are major components of extracting biofuels from plants. Modification of above mentioned components are the main objectives of making GM plants. The modification of plants is depends upon the crop species, the objectives of improvement
- Some plants species have more sugar whereas other plants have much oil contents. In general, obtaining fast growing crops, high sugar or starch content plants, plants contain more cellulose or less lignin, plants use less water and have greater degree of resistance to insects and disease and herbicides as well are considerable characteristics to make transgenic plants for biofuels

GMO production technology

- 1) Vector mediated or indirect gene transfer: *Agrobacterium* or viral vector

- 2) Vector less or direct gene transfer: chemical mediated gene transfer, microinjection, electroporation, particle gun or particle bombardment.

GMO crop

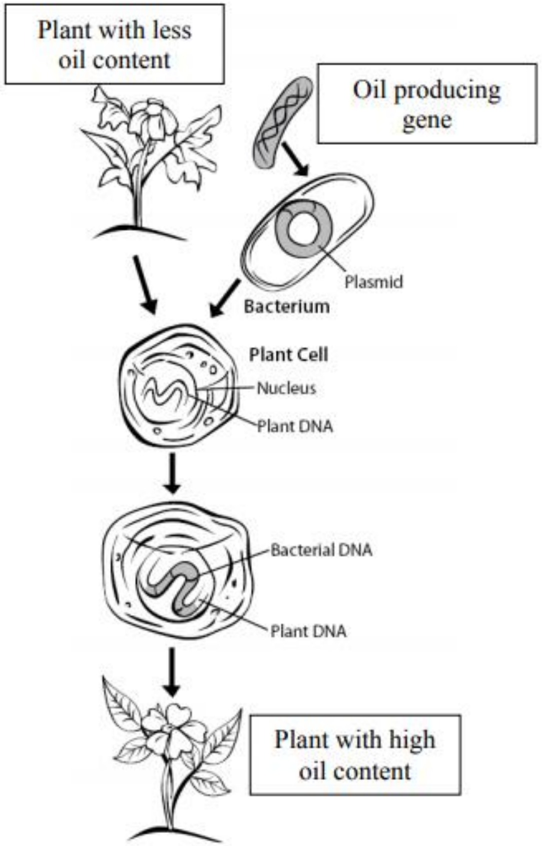


Figure 2.1. Process of creating a transgenic plant

GMO: improving efficiencies

- Reduced need for fertilizers

- Nutrients are most important factors for growth and development of plant. There are more than 16 nutrients have been identified for plant growth.

- Among them nitrogen, phosphorus, and potassium are major elements. The element like nitrogen is the largest constituent of the atmosphere, about 80%.

- Nitrogen deficient plants couldn't develop very well and ultimately the performance of plants goes down.

- So some plants like legumes trap the atmospheric free nitrogen for its own growth and development. Nitrogen fixation in legumes crops involved many bacterial strains.

- With application of genetic transformation non-legume crops are also able to fix the atmospheric nitrogen, so that it reduces the application of huge amount of fertilizers in fields to produce more biomass.

GMO: improving efficiencies

- Furthermore, scientists identified an enzyme called glucin dehydrogenase which involved in utilization of fertilizers in plants. The gene for glucin dehydrogenase is present in most of crops; however the expression level is varies with crop by crop (Rader, 2008).
- With the help of genetic transformation, we can increase the expression level of the gene on biofuel crops thereafter; ultimately increase the yield of crop from same field

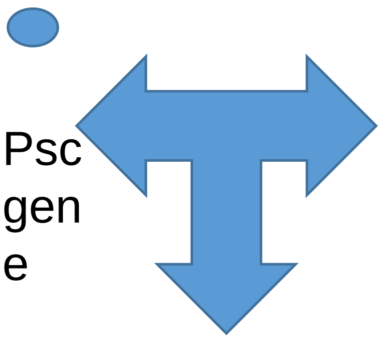
GMO: improving efficiencies

- **Improving solar energy use efficiency**

- Plant produces sugar from water and CO_2. For this purpose solar energy is most important. The photosynthesis rate varies from crop to crop. For instance, corn plants make more sugar per unit of sunlight than any of the other grains. So that could be possible to increase per unit sugar by improving the light energy efficiency, because the photosynthetic gene found in corn plant which is not present in rice plant (Rader, 2008).

GMO: improving efficiencies

- Furthermore, carbohydrates are most important for growth and development of plants and always allocate toward the growing parts. To date the gene is identified responsible for partitioning for carbohydrate in corn plants.
- The gene is Psychedelic (psc) which controls the distribution of carbohydrates on growing parts like flowers (Slewinski and Braun, 2010), so that if we modify such gene only distributing on leaves and stem then we could able to get more biomass and obviously have more ethanol from corn plants.



Psc gene

Weak plant

Strong plant with more leav

GMO: improving efficiencies

- Increasing cellulose contains and decreasing hemicellulose fraction on maize plants not only increases the bioethanol production but also improve the digestibility to livestock (Dhugga, 2007). Additionally, lignin is the most important part of plants for making rigid structures.
- The lignin is the one of lowest biofuel producing organs on plants. By means of genetic engineering we can remove the lignin from plant; however it does not make a sense. Without lignin very hard to get plant stand in earth surface. Thus, the objective for biotechnologists could be possible to make plant having easily degradable lignin. Furthermore, we can modify the biosynthesis of lignin molecules, structural rigidity, etc.

Negative impacts of GMO

Gene flow

- Accidental cross breeding between GMO plants and traditional varieties through pollen transfer can contaminate the traditional local varieties with GMO genes resulting in the loss of traditional varieties of the farmers

Negative impacts of GMO

- When farm lands are using for biofuel production ultimately reduce the farmland. That's why increasing food prices and the world tend to hunger.
- The existing area for cultivation is not sufficient to fulfill the energy requirements so that more cultivation area should have increase. The only options for increasing farming land by reducing the forest land due to which cause net increase in greenhouse gases

Negative impacts of GMO

- Increase the dependency on eco-destructive pesticides to defense against the pest.
- Proliferation of dangerous genetically modified crops.
- Genetically modified crops are dangers in the sense that they have linked to organ damage and reproductive failure in mammals, sudden death and complete failure of crops.
- Social, religious and ethical issues

GM YEAST

- Glucose and xylose are two of the major components of hydrolysates from lignocellulose
- Therefore, the efficient conversion of xylose to ethanol is essential for successful utilization of lignocelluloses
- *Saccharomyces cerevisiae*, which is extensively used in the conversion of glucose into ethanol, has some advantages due to its high ethanol productivity, high tolerance to ethanol and high inhibitor tolerance

GM Yeast

- *S. cerevisiae* is unable to utilize xylose naturally
- Whereas it can metabolize xylulose to ethanol. Xylose can be converted into xylulose by introducing XYL1 encoding for NADPH-linked xylose reductase (XR) and XYL2 encoding for NADlinked xylitol dehydrogenase (XDH) from the xylose fermenting yeast, *Pichia stipitis*

GM yeast

- Improvement in ethanol production can be achieved by partially reducing the major by-product (glycerol production) during glucose fermentation
- GPD1 and GPD2, two glycerol-3-phosphate dehydrogenases, are key enzymes in glycerol synthesis by *S. cerevisiae*. Deletion of these can increase ethanol production significantly
- FPS1, a glycerol channel protein, controls glycerol excretion from the intracellular to extracellular space and its deletion also improves the ethanol production

Glucoamylase expressing *S. cerevisiae* For starch platform ethanol

- Construction of a yeast strain that can utilize raw starch has been studied since the 1980s
- In the beginning of genetically engineered S. cerevisiae, fashioned for starch fermentation, 13% (v/v) ethanol yield was obtained from direct hydrolysis of starch via using glucoamylase expressing yeast
- First step of the process began by constructing recombinant strains that express amylolytic enzymes (α-amylase or glucoamylase) for the liquefaction and saccharification of the starchy biomass (For simultaneous saccharification and Fermentation (SSF))

Glucoamylase gene

- Glucoamylase (1,4-α-D-glucan glucohydrolase; EC 3.2.1.3) is recognized as the most important enzyme which is responsible for the progressive hydrolysis of starch from non-reducing ends to release β-D-glucose units and saccharification of the polymers
- The glucoamylase cDNA gene (glu) from *Aspergillus awamori* has been successfully incorporated into *S. cerevisiae* genome for the utilization of starch and recombinant strains have been found to be stable for 50 generations without applying any selective pressure
- A recombinant *S. cerevisiae*, SR93, modified to express glucoamylase has produced more ethanol (24.9 $g.l^{-1}$) as compared to a co-culture of *A. awamori* and wild type S. cerevisiae system (22.0 $g.l^{-1}$)

GM Algae

- Considering the current rapid rate of fossil fuel depletion, many countries are heavily investing in biofuel generation from algae and including the use of genetic modification (GM) research to enhance their baseline biofuel qualities
- GM algal strains are being investigated to make algal biofuel commercially competitive to fossil fuels
- However, the commercial mass cultivation of GM algae in open ponds with the potential impact of escape into the environment is an important concern. In addition, concerns exist over the potential that GM algae can form new GMO combinations via sexual reproduction with their wild-type counterparts or via horizontal gene transfer to cyanobacteria
- Cyanobacteria have been more popular candidates for genetic transformation than green algae due to their greater receptiveness to the incorporation of foreign genes

GM algae: Green Algae

- The genetic engineering of green algae is still at a primitive stage and the stability of the transgene in the modified organism genome is still a source of uncertainty, which makes them currently unsuitable for immediate commercial release
- green algae are haploid in nature and have a tendency to reproduce asexually, both attributes helping to minimise the potential for transgene escape
- Counter measures can be incorporated into the design of GM algae in order to reduce their survival potential should they escape into the natural environment
- Many countries are facing a deadlock over the approval of field trials of GM crops due to the indecisiveness of the GMO regulatory authorities

GM Algae

- The green algae *Chlamydomonas reinhardtii* has been genetically modified to express several important traits of biofuels (limitation - low biomass production rates and lipid content)
- Major green algal species, such as *Chlorella, Parachlorella, Nannochloropsis, Scenedesmus, Botryococcus, and Neochloris* have been identified as being rich in lipid content and thus as potential candidates for biofuel production
- Genetic modification has largely been limited to formative studies transferring reporter genes and/or selectable marker genes, only two species, *Chlorella* and *Dunaliella*, transformed with biofuel-related traits (For biohydrogen)

GM algae

Algal Species	Genetic transformation with biofuel related traits
Chlorella	Hydrogenase (*HydA*)
Dunaliella	Xylanase, α-galactosidase, phytase, phosphate anhydrolase, and β-mannanase

GM Algae: Blue-green algae

- Cyanobacteria may be engineered to produce other important biofuel-related molecules due to their ability to grow in extreme environments and the relative ease of their genetic transformation.
- In cyanobacteria, most genetic engineering has been carried out in model organisms, *Synechocystis sp. PCC 6803, Synechococcus elongatus sp. PCC 7492, Synechococcus sp. PCC 7002 and Anabaena sp.* PCC 7120
- Cyanobacteria fix CO_2 more efficiently than plants, and can be engineered to produce carbon feedstocks useful for biofuel. However, extension of this technology to commercial levels is disappointing due to the current low yields.

CONTAINMENT OF GM ALGAE

- Enclosed system and photobioreactors

CONTAINMENT OF GM ALGAE

- Outdoor open ponds with water buffer zones

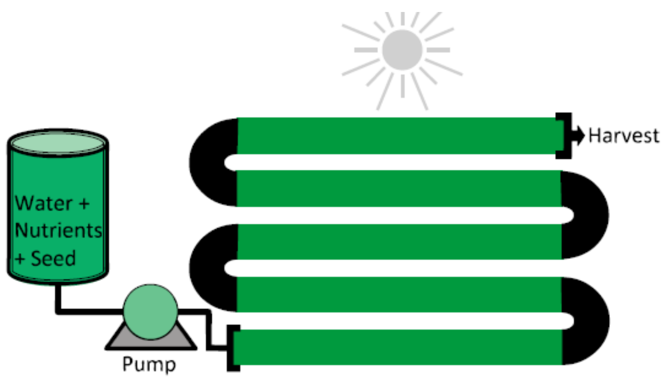


Figure 1. **Outdoor cultivation of GM algae in an enclosed system to tap solar energy for growth. Such a system may be suitable for temperate climates to scale-up GM algae culture.**

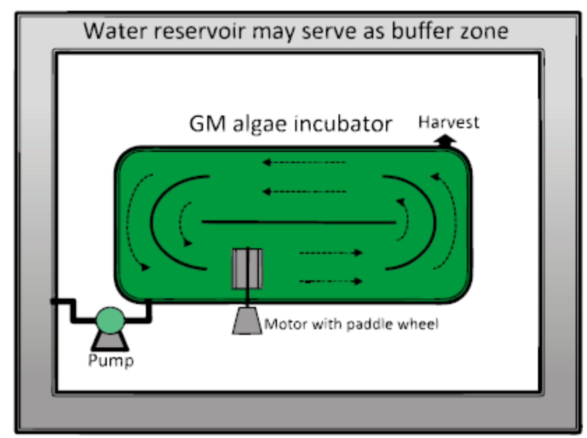
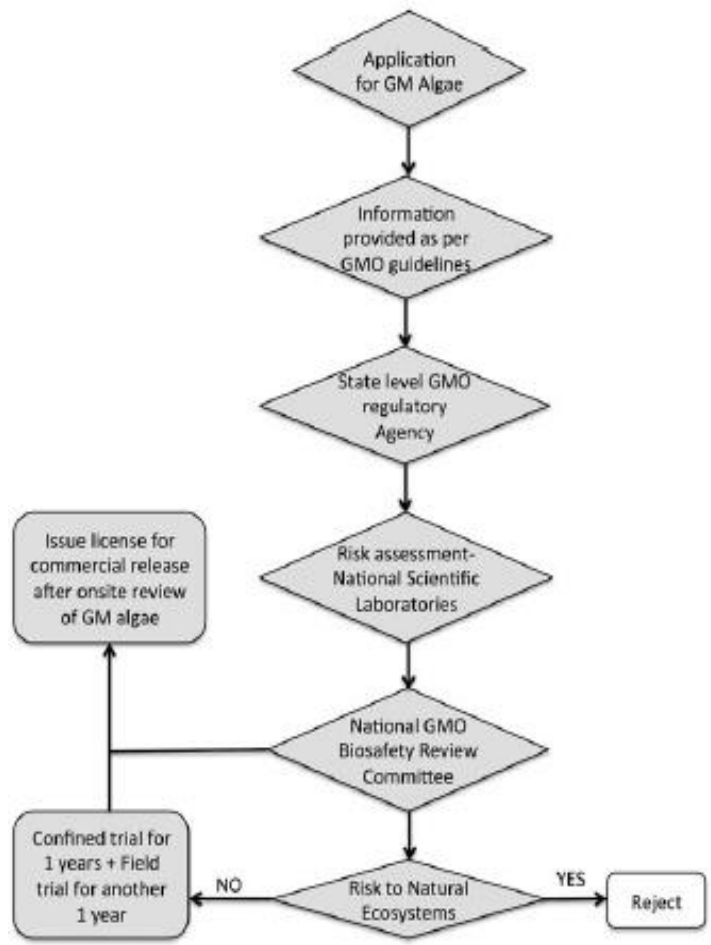


Figure 2. **Outdoor cultivation in an open pond surrounded by a water reservoir buffer zone (~6-10 ft wide) to isolate the GM algae from any surrounding natural ecosystems.** In addition to acting as a physical barrier, the water reservoir may also be used to store the nutrient-supplemented water or medium for cultivating GM algae.

Theoretical decision-making tree for GM algae authorisation



POLYOLS and ORGANIC ACIDS

Definition

Polyols are polymers that contain multiple hydroxyl groups in their structure. They are generally produced from petroleum derivatives or lignocellulosic biomass and have a relevant commercial value as building blocks, intermediates in organic synthesis, or precursors for production of polyurethanes

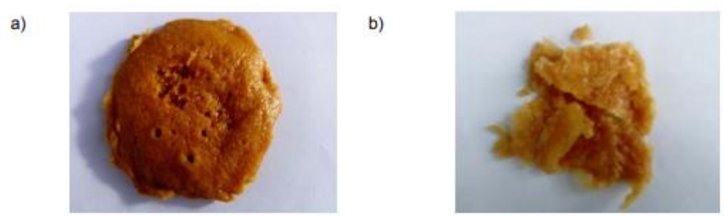
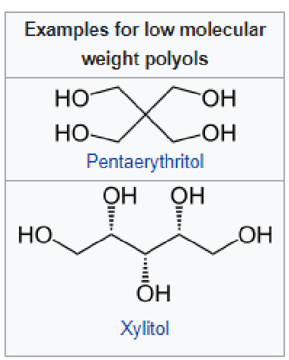


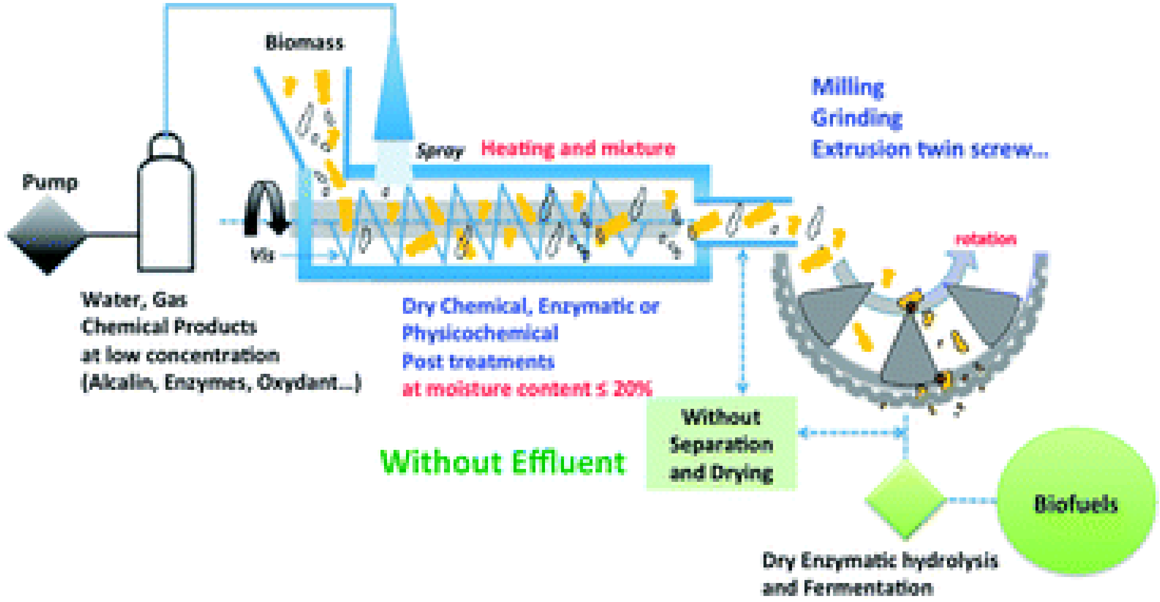
Figure 3: Visual aspect of obtained polyurethanes. a) from cooking oil, b) from castor oil



A polyol is an organic compound containing multiple hydroxyl groups. The term "polyol" can have slightly different meanings depending on whether it is being used in the field of food science or that of polymer chemistry. A molecule with more than two hydroxyl groups is a polyol, with three – a triol, and with four – a tetrol. By convention, polyols do not refer to compounds that contain other functional groups.

- lignocellulosic biomass is used as one part of the raw material for liquefaction.Generally, lignocellulosic biomass refers to agricultural wastes (corn stover, wheat straw, rice stalk, soybean straw, etc.), wood wastes (dead trees, wood chips, sawdust, etc.), and other types of plants, industrial paper pulp, herbals and so on.

- The lignocellulosic biomass material typically is reduced in size to facilitate liquefaction. In accordance with certain aspects, the material can be chopped into pieces. It can also be milled to provide the appropriate size particles. The liquefaction process in accordance with certain embodiments utilizes biomass particles below about 50 mm, more particularly below about 20 mm.



Polyol production

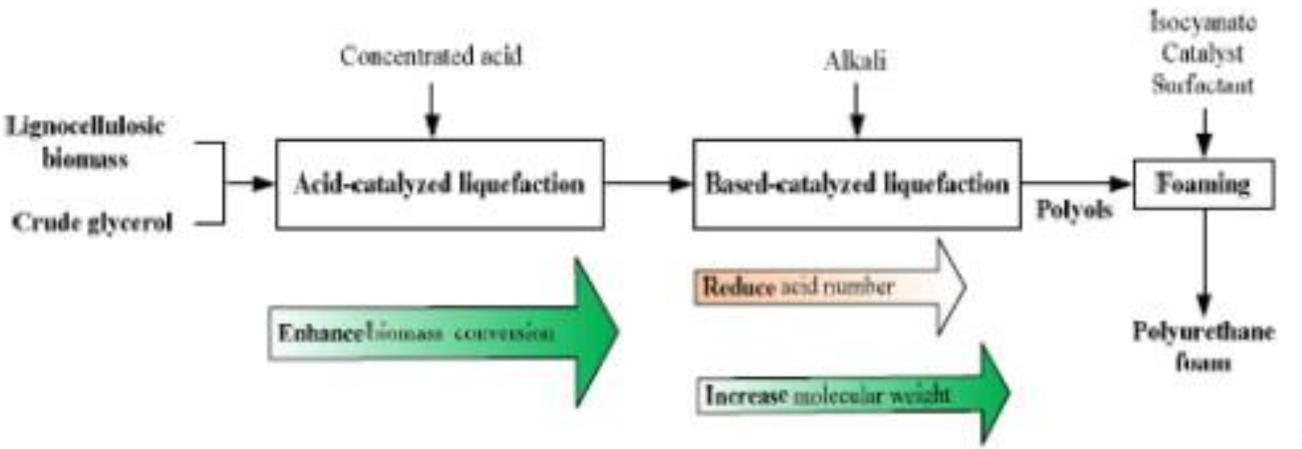
- Acid-catalyzed process
- Base-catalyzed process
- A two-step sequential biomass liquefaction process
- The first, acid catalyzed, step rapidly liquefied biomass and promoted the esterification reactions between glycerol and FFA.
- while the second, base-catalyzed, step facilitated extensive condensation reactions such as transesterification and etherification that occurred among liquefaction components.

- LIQUEFACTION PROCESS
- Liquefaction of soybean straw using biodiesel derived crude glycerol as a liquefaction solvent.

- Under optimal liquefaction conditions (240 °C, 180-360 min, 3 % sulfuric acid loading, and 10-15 % biomass loading), the polyols produced had hydroxyl numbers ranging from 440 to 490 mg KOH/g, acid numbers below 5 mg KOH/g, and viscosities from 16 to 45 Pa·s.

- PU foams were produced directly from the produced polyols and had densities ranging from 0.033 to 0.037g/cm3 and compressive strength from 148 to 203 kPa. Certain impurities in crude glycerol improved the properties of the polyols and PU produced.

A two-step sequential biomass liquefaction process



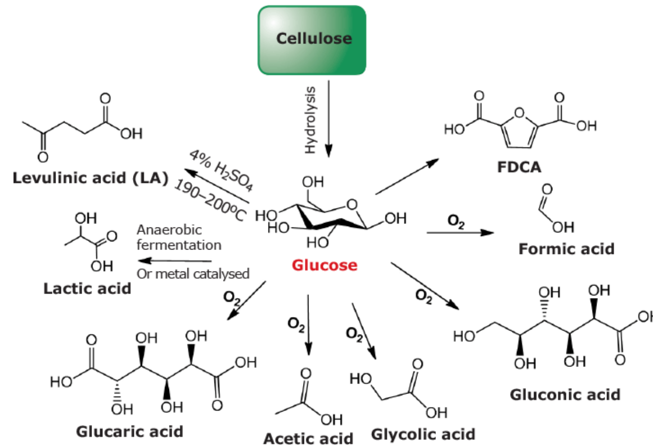
Polyols were produced via a sequential two-step liquefaction of lignocellulosic biomass using biodiesel-derived crude glycerol as a liquefaction solvent. This two-step process combines the virtues of both acid- and base-catalyzed biomass liquefaction processes. The produced polyols are suitable to prepare high-quality rigid or semi-rigid polyurethane foams that are commonly used as insulation materials.

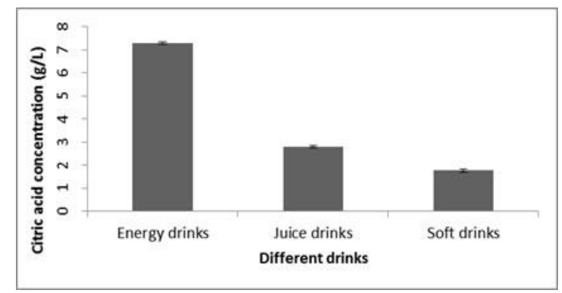
Advantages of acid catalysis over base-catalysis

- Compared to the base-catalyzed process, the acid-catalyzed process featured faster biomass liquefaction and produced polyols with lower viscosities but higher acid numbers.
- However, the acid-catalyzed process needed crude glycerol with high glycerol content (≥ 50 %) to prevent early occurrence of detrimental condensations, whereas no detrimental condensations were observed in the base-catalyzed process.
- Moreover, in contrast to their negligible effects on the base-catalyzed process, inorganic salts, including NaCl and Na2SO4, negatively affected the properties of polyols produced from the acid-catalyzed process.

Organic acid production from plant biomass

- Organic acids are widely used in the chemical, food, cosmetic, pharmaceutical, and beverage industries owing to their various functional properties.
- Furthermore, the nematicidal effect of organic acids in the field of biological control has been extensively reported.
- The global organic acid market was estimated to reach $6.94 million by 2016 and is expected to increase annually to $12.54 billion by 2026, based on the organic acid market analysis report.
- In general, organic acids are produced by chemical synthesis, which results in serious environmental pollution worldwide. Therefore, process optimization and development of high-efficiency bacterial strains are indispensable for organic acid production using eco-friendly biotransformation of agricultural waste. Organic acid production from biomass is produced by hydrolysis and fermentation (SHF) and simultaneous saccharification and fermentation (SSF) processes.

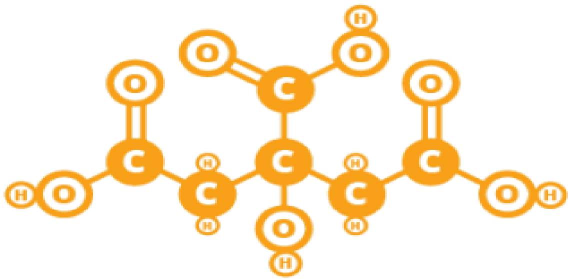




Microbial citric acid instead of lemon derived to add in beverages like Sprite, 7 up etc.

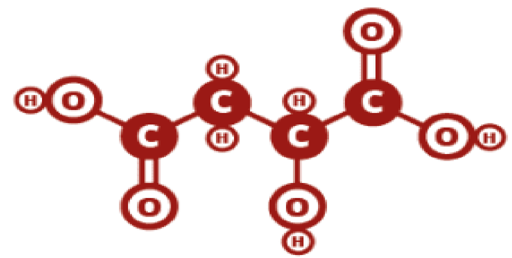
A GUIDE TO COMMON FRUIT ACIDS

Most people probably know that lemons and other citrus fruits contain citric acid – but it's just one of a number of different organic acids that can be found in fruits. Here we look at a number of the most common acids, and the various fruits that they are found in.

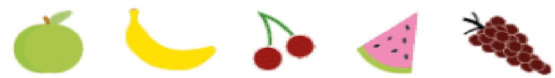


CITRIC ACID

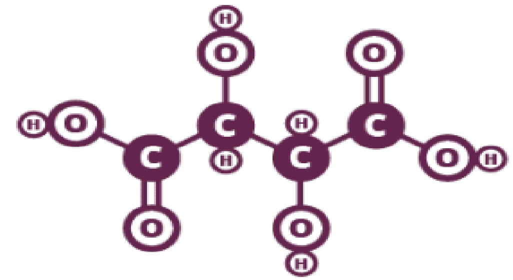
The main acid in citrus fruits is, unsurprisingly, citric acid. Lemons and limes have particularly high levels of this compound. It is also the main acid in a number of berry fruits, including strawberries, raspberries and gooseberries.



MALIC ACID



Malic acid is the main acid in most stone fruits such as cherries, apricots, peaches, and nectarines. It's also found in high amounts in apples, and in lower amounts in bananas. Though watermelons have a low acid content, their principle acid is also malic acid.

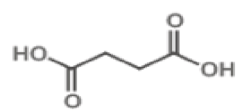


TARTARIC ACID

Tartaric acid is the principle acid in fewer fruits than citric and malic acid. However, it is the main acid in grapes, which also contain malic acid. Red grapes have higher levels of tartaric acid. The main acid of avocado and tamarind is also tartaric acid.

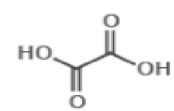
OTHER ORGANIC ACIDS

Citric, malic, and tartaric acids are not the only organic acids present in fruit – a number of other acids are also present, albeit in significantly smaller quantities. To the right, a small selection of these compounds are shown, along with a brief note of some of the fruits in which they're often found.



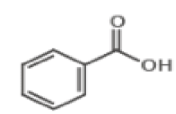
SUCCINIC ACID

Apples and some berries



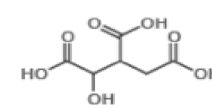
OXALIC ACID

Small amounts in berries



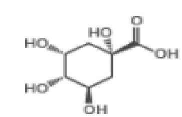
BENZOIC ACID

Present in cranberries



ISOCITRIC ACID

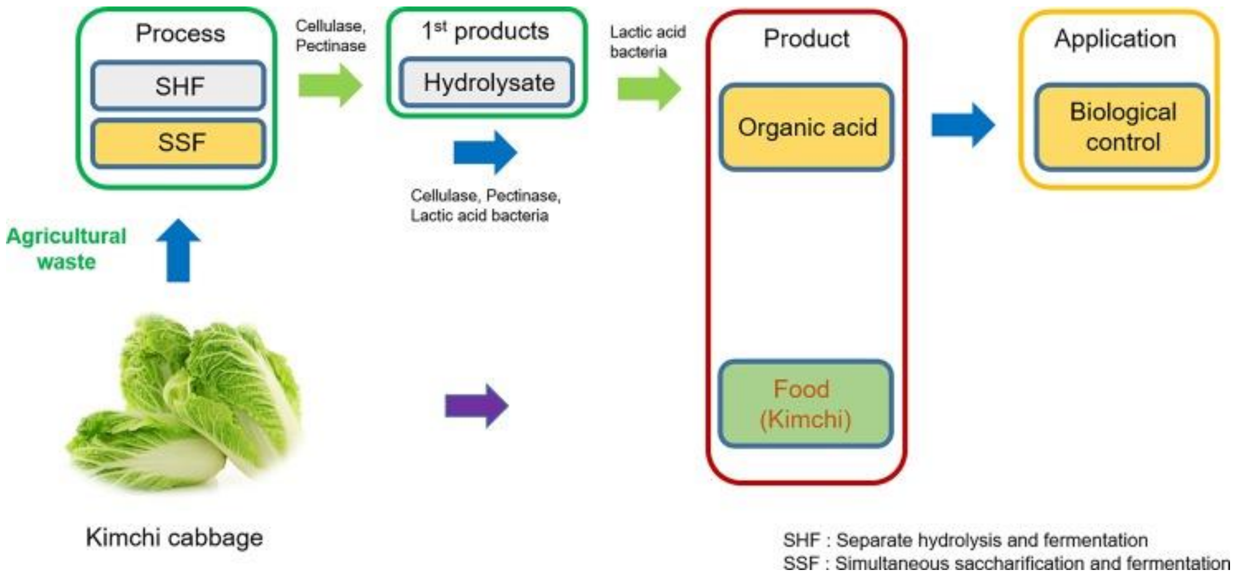
Present in blackberries



QUINIC ACID

Plums & kiwifruit

Kimchi cabbage is one of the major agricultural products cultivated worldwide to produce organic acid



Strain: *Lactobacillus sakei*

Separate hydrolysis and fermentation (SHF)

- To attain economic feasibility of SHF of KCW, high organic acid production efficiency must be achieved.
- The SHF process can result in a higher production yield compared with that of the SSF process because of the optimization of the enzymatic hydrolysis and fermentation process.
- Therefore, the enzymatic hydrolysis and fermentation process was conducted at 45°C and 30°C, respectively.

Pilot plant for lignocellulosic based chemicals synthesis

Simultaneous saccharification and fermentation (SSF)

- SSF is recognized as the most common method where 2 and 3rd reactor is combined as one.
- In fact, SSF can reduce the capital cost, substrate inhibition, and overall process time compared with SHF.
- The growth of LAB stains *W*. *cibaria* WiKim28, *L*. *sakei* WiKim31, and *L*. *curvatus* WiKim38 was reduced at temperatures above 35°C, so the SSF processes were conducted at 32°C.

Advantage of SSF over SHF

- The SHF processes showed slightly more efficient production of organic acid than the SSF processes because of the optimization of the enzymatic hydrolysis and fermentation process.
- However, SSF processes of *L. sakei* WiKim31 and *L. curvatus* WiKim38 showed a tendency to rapidly produce high amounts of lactic acid with KCW of 4.5% (w/v) and 6.0% (w/v) within 24 h of reaction compared with SHF processes).
- The SSF processes have been extensively studied for the production of organic acid because of the high production yield.
- Consequently, considering the economic feasibility, SSF is considered to be more suitable than SHF for the production of organic acid from KCW.

Summary: Plant derived value added chemicals