Controlling CO_2 Emissions

Course: **Fabrication of solarcells**
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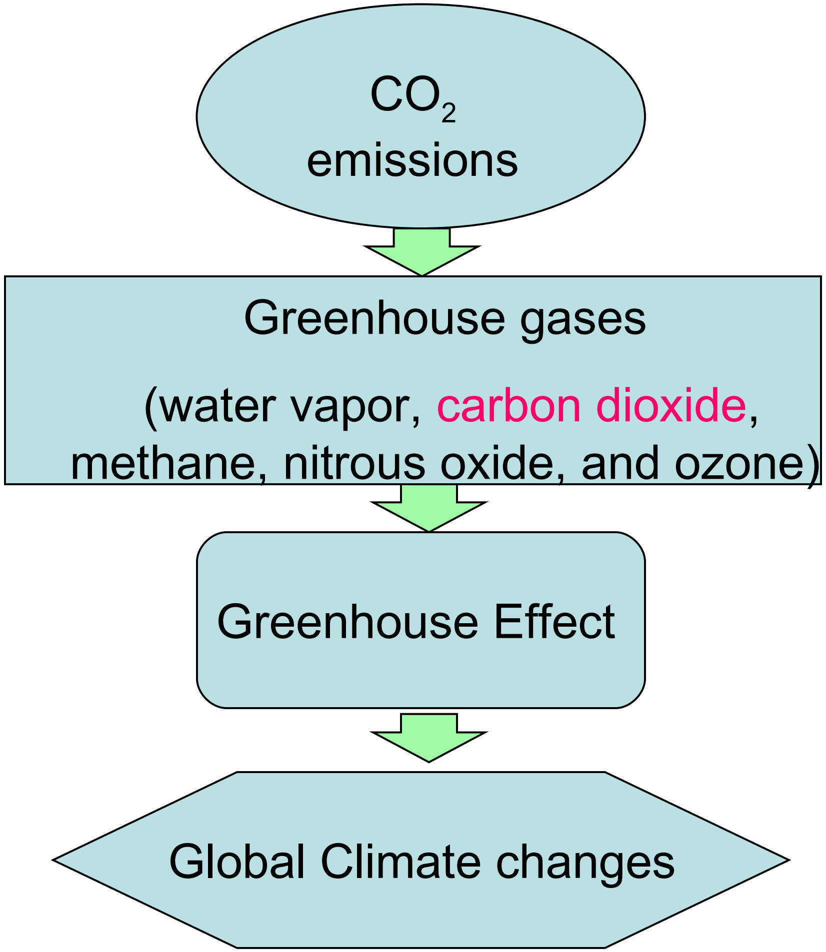
Student presentation: Le Van Vinh

Controlling CO_2 Emissions

- Why do we need to control CO_2 emissions?



The major natural greenhouse gases

Water vapor:

which causes about 36-70% of the greenhouse effect on Earth

Carbon dioxide:

which causes:

9-26%

Methane:

which causes:

4-9%

Ozone:

which causes:

3-7%

❖ It is not possible to state that a certain gas causes a certain percentage of the greenhouse effect, because the influences of the various gases are not additive.

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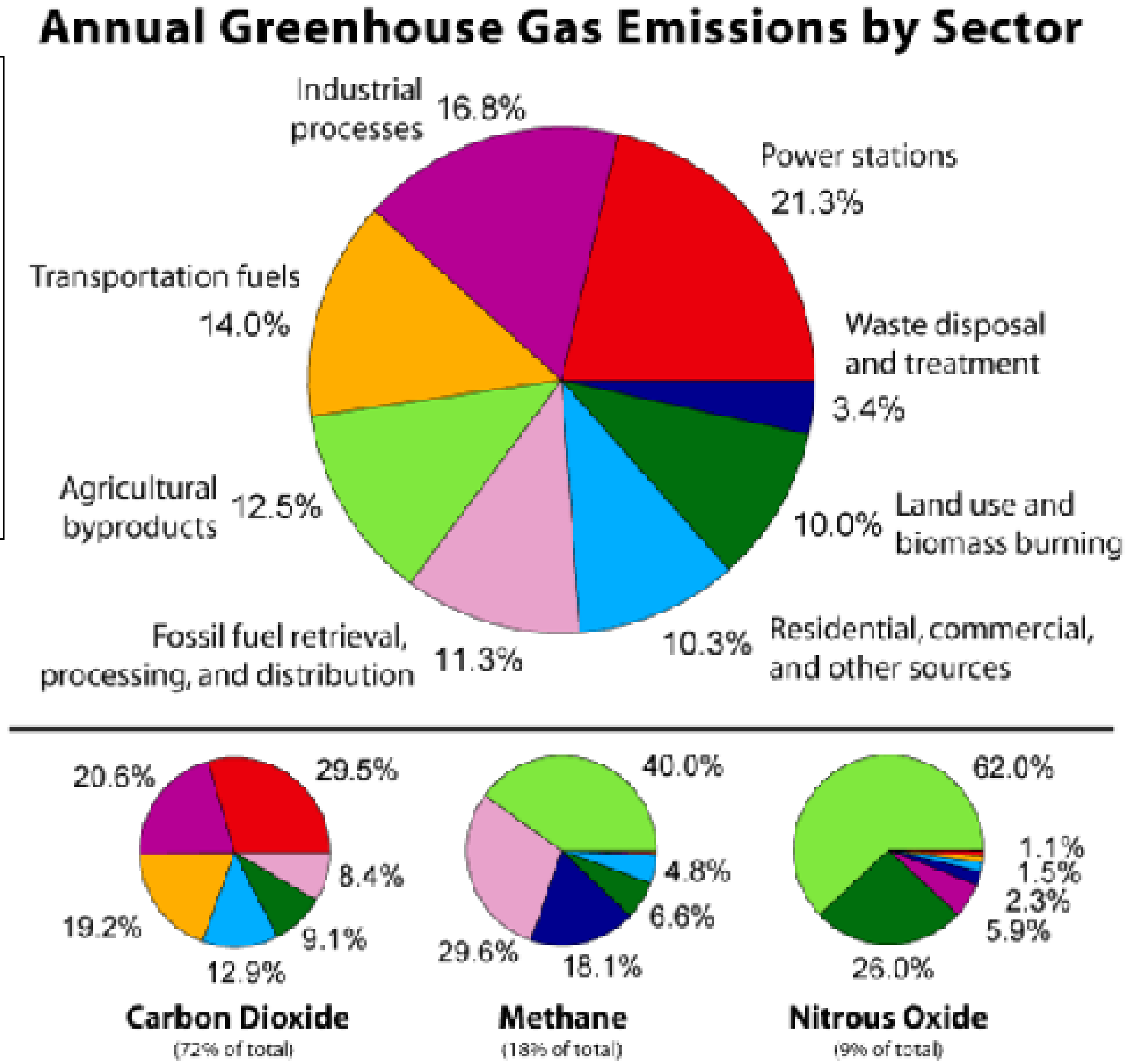
[1] *Bulletin of the American Meteorological Society* ***78*** *(2): 197-208. Retrieved on 2006-05-01.*

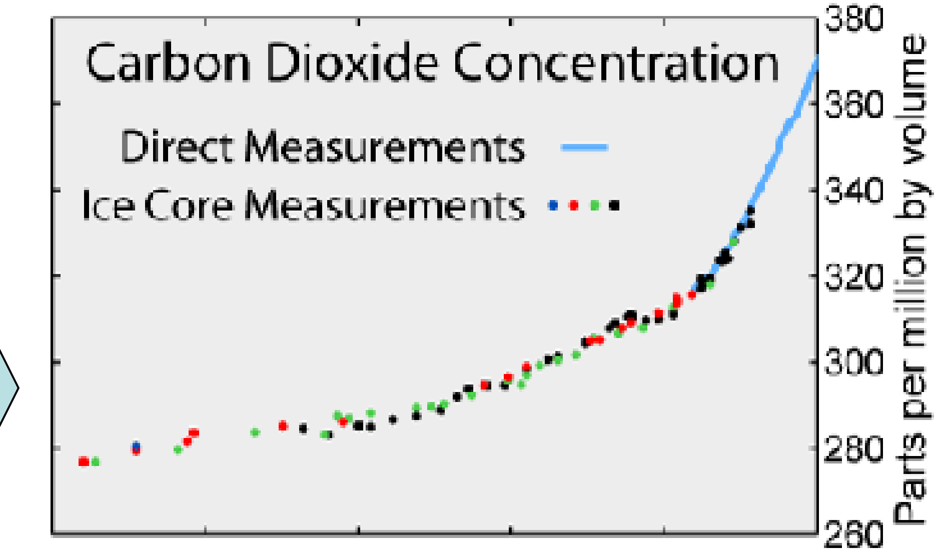
[2] *Water vapour: feedback or forcing?. RealClimate (6 Apr 2005). Retrieved on 2006-05-01.*

The relative fraction of man-made greenhouse gases

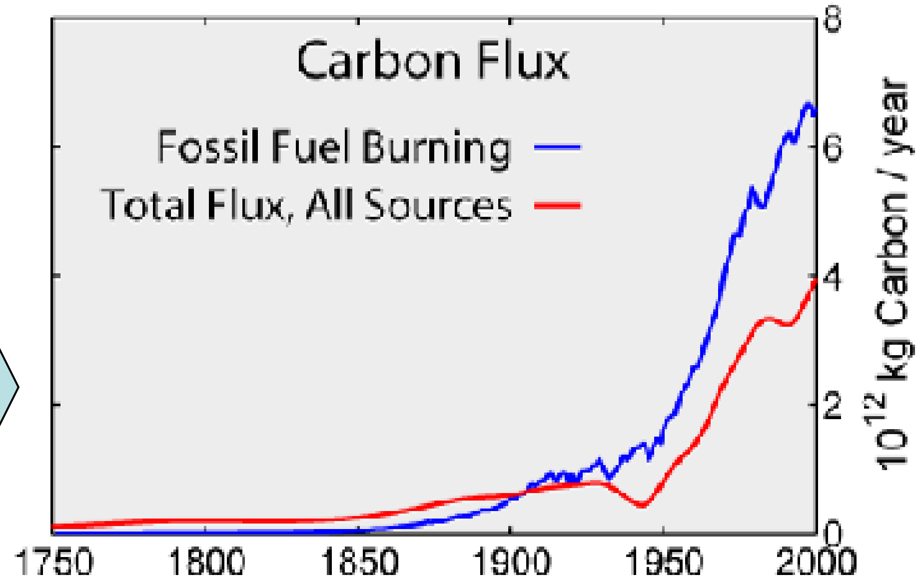
(
Emission Database for Globa
version 3.2, fast track 2000 project - global annual greenhouse gas emissions in the year 2000)



Increasing atmospheric CO_2 levels as measured in the atmosphere and ice cores

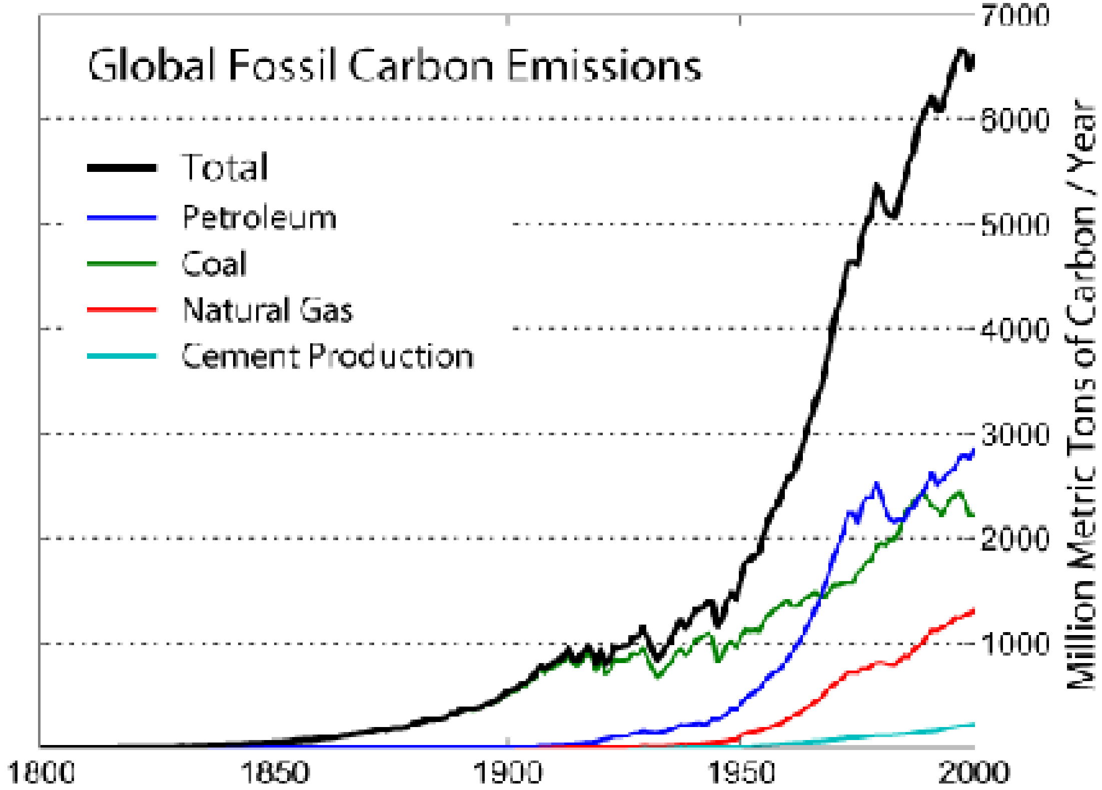


The amount of net carbon increase in the atmosphere, compared to carbon emissions from burning fossil fuel.



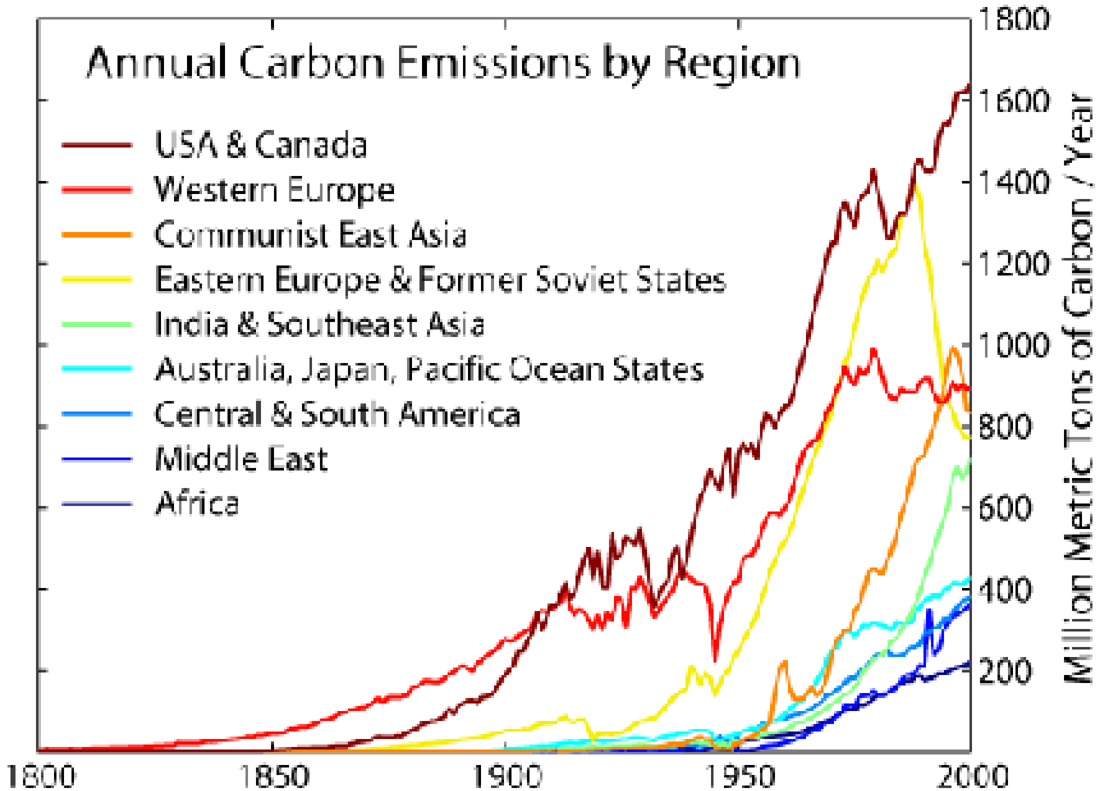
References:

[1] Keeling, C.D. and T.P. Whorf (2004) "Atmospheric CO2 records from sites in the SIO air sampling network" in *Trends: A Compendium of Data on Global Change.* Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.



Global annual fossil fuel carbon dioxide emissions, in million metric tons of carbon

Original data: Marland, G., T.A. Boden, and R. J. Andres. 2003. "Global, Regional, and National CO2 Emissions." In *Trends: A Compendium of Data on Global Change.* Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. http://cdiac.esd.ornl.gov/trends/emis/tre_glob.htm



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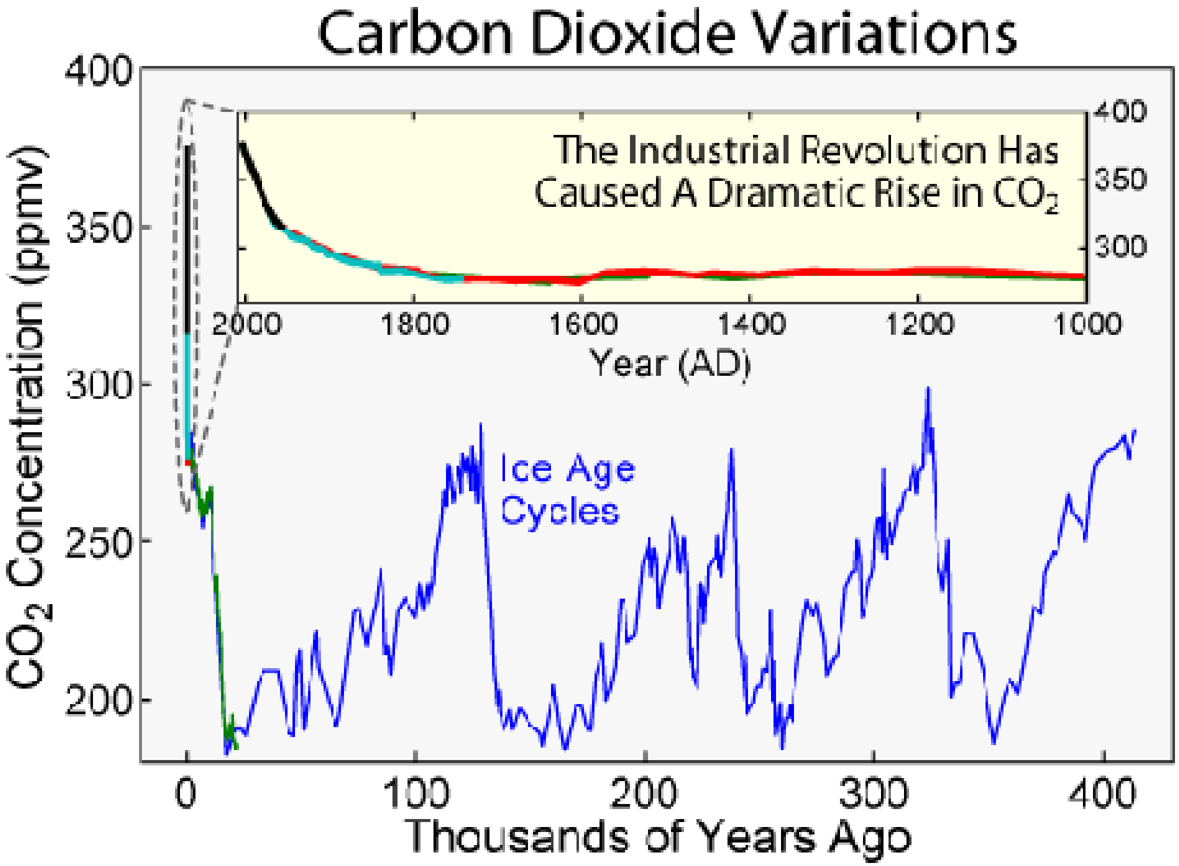
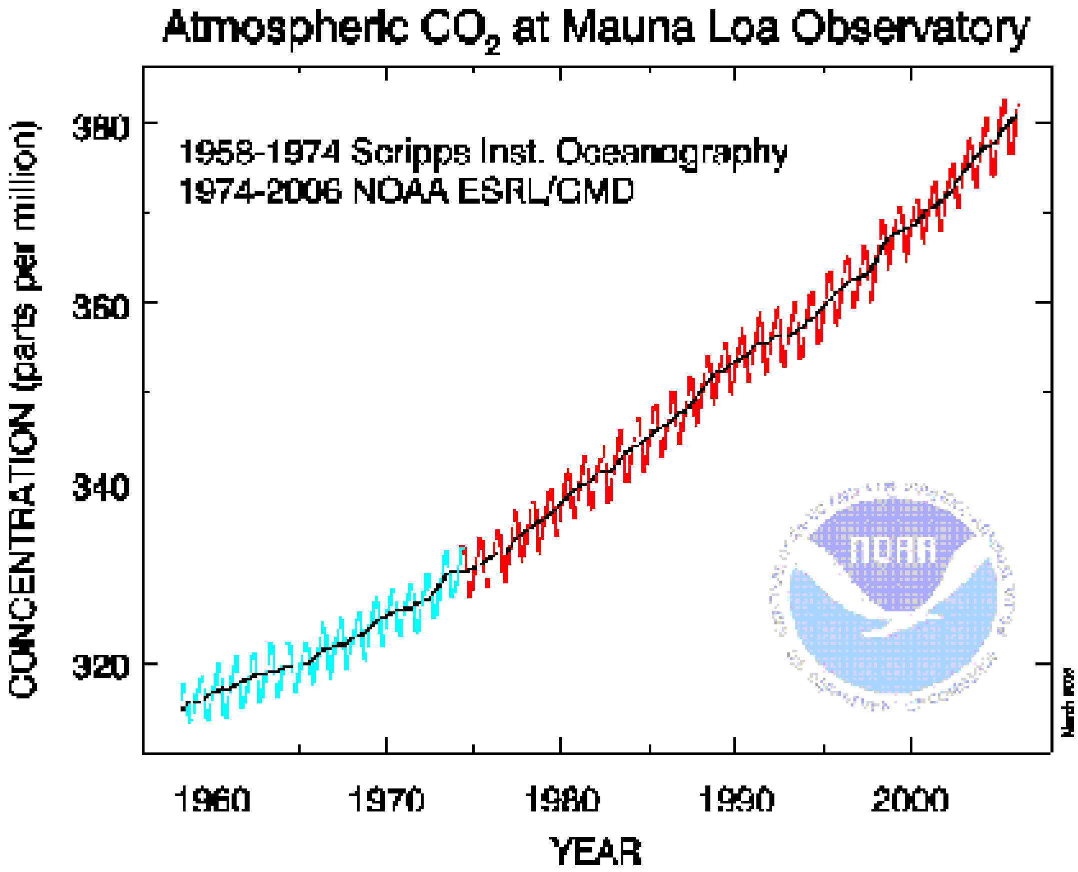


the variations in concentration of carbon dioxide (CO2) in the atmosphere during the last 400 thousand years.

Original data: Marland, G., T.A. Boden, and R. J. Andres. 2003. "Global, Regional, and National CO2 Emissions." In *Trends: A Compendium of Data on Global Change.* Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. http://cdiac.esd.ornl.gov/trends/emis/tre_glob.htm



A graph depicting CO2 levels. The cause for the yearly rise and fall is the annual cycle of plant respiration.

Original data: C.D. Keeling, T.P. Whorf, Scripps Institution of Oceanography (SIO).

Emission reductions of CO_2

A combination of several of the following approaches:

- **End-use efficiency improvements and conservation.**
- **Supply side efficiency improvements.**
- **Capture and sequestration of CO_2 in subterranean reservoirs or in the deep ocean.**
- **Utilization of CO2 for enhanced oil and natural gas recovery and for enhanced biomass production.**
- **Shift to nonfossil energy sources.**

End-Use Efficiency Improvements and Conservation

- In the residential-commercial sector:
  - Lowering the thermostat in the winter (less heating), raising it in the summer (less air conditioning), better insulation, less hot water use, using fluorescent lighting, and so on.
- In the industrial sector:
  - The largest savings could come from reductions in direct use of fossil fuels, process modification, energy-efficient motors, better heat exchangers, and so on.
- In the transportation sector:
  - Smaller, lightweight automobiles to hybrid electric-internal combustion engine or fuel-cell-powered vehicles.

Supply-Side Efficiency Improvements

- Mean principally electricity supply by supply-side efficiency Improvements.
- Options to reduce carbon emissions:
  - Shift from coal to natural gas.
  - Replacement of single-cycle gas-fired steam power plants with combined cycle gas turbine plants (CCGT).
  - Replacement of single-cycle coal-fired power plants with gas-fired CCGT.
  - Replacement of single-cycle coal-fired power plants with coal-derived synthetic gas-fired combined cycle gas turbine plants.

CO_2 Capture

- The volume fraction of CO_2 in the flue gas of fossil fuel electric power plants ranges: 9% to 15%.
- The Capture of CO_2 is quite difficult and expensive.
- The Capture of CO_2 is only worthwhile in large power plants. (a 1000-MV coal-fired power plant emits: 6 to 8 Mty^{-1} of CO_2)

➢ So, The Capture of CO_2 from all the world's large coal-fired power plants would make a significant dent in the global carbon emissions.

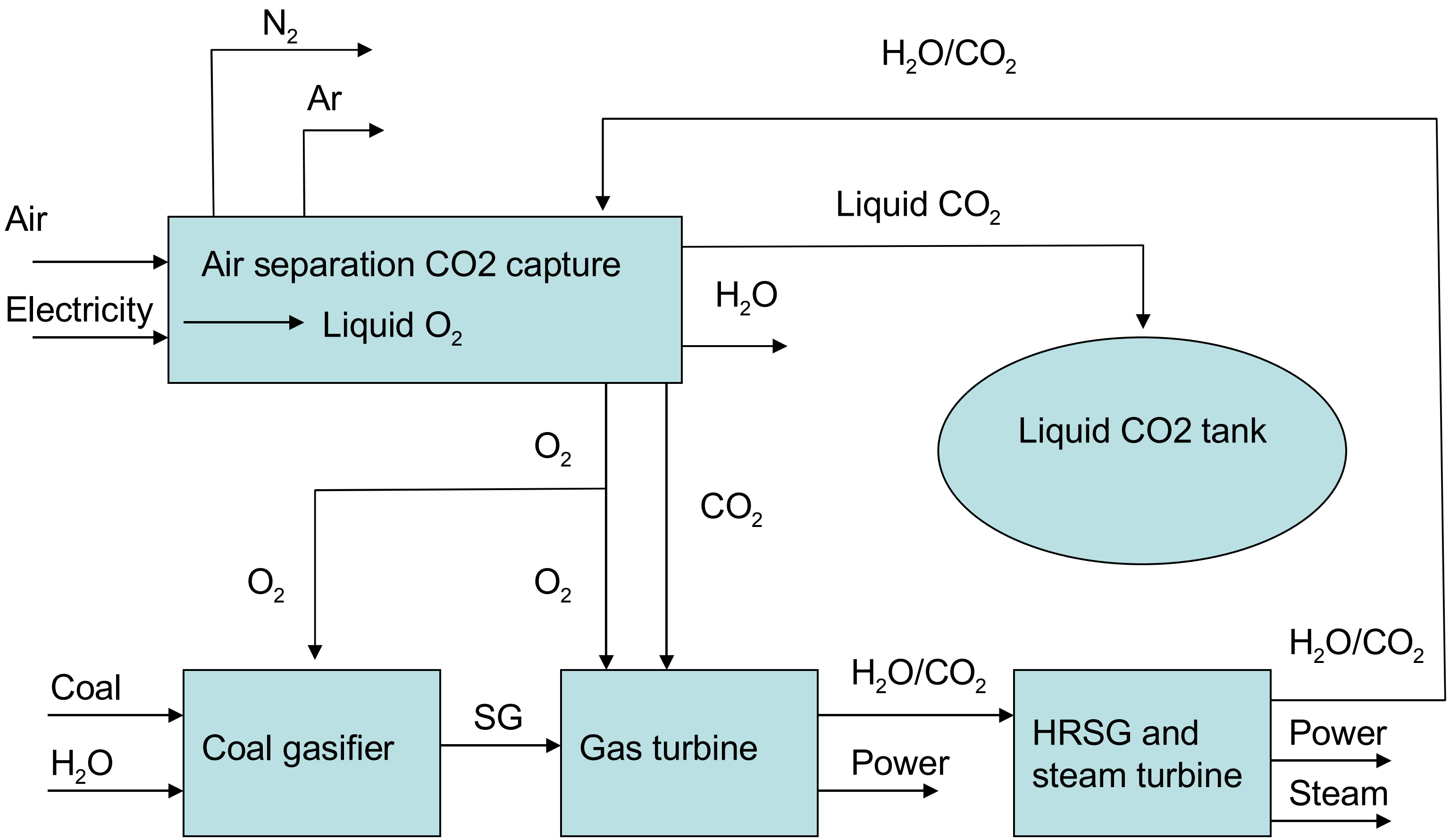
The technologies for CO_2 capture from power plants

- Air separation-CO_2 recycling
- Solvent absorption
- Membrane gas separation

Air Separation-CO_2 Recycling

- This method is based on combustion of the fossil fuel in pure oxygen, instead of air.
- A plant using this method requires an air separation unit.

Air Separation-CO_2 Recycling

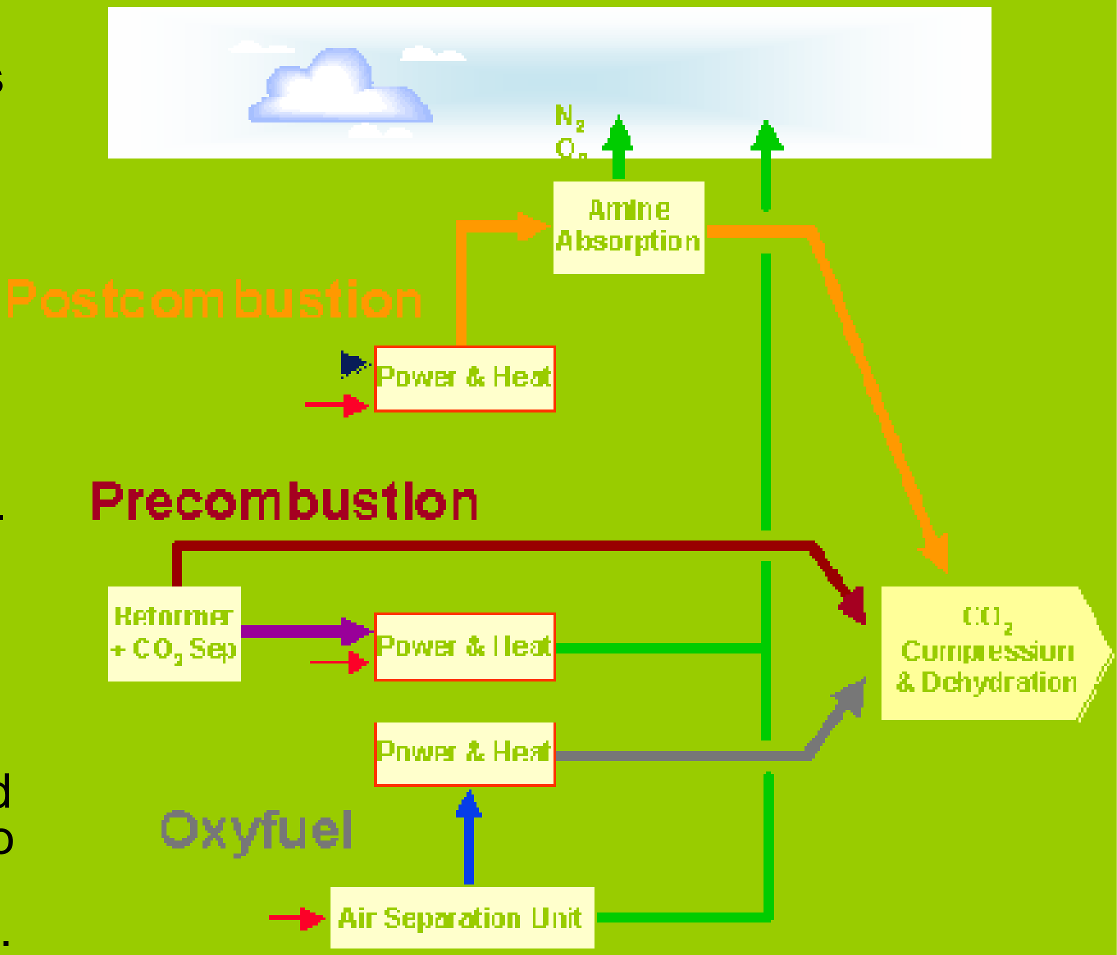


Schematic of an integrated coal gasification combined cycle power plant with CO_2 capture

-Heat recovery steam generator (HRSG);

Capture Technologies

1. **Post-Combustion Scrubbing**
   Considered the first step towards large-scale capture, CO2 is removed from exhaust gas after combustion. This technology can be retrofitted to existing equipment.
2. **Pre-Combustion Decarbonization (Hydrogen)**
   Natural Gas is converted to hydrogen and CO2 in a reformer. The CO2 is compressed for storage and the hydrogen is mixed with air for combustion, emitting only nitrogen and water.
3. **Oxyfuel**
   Oxygen is separated from air and then burned with hydrocarbons to produce an exhaust with a high concentration of CO2 for storage.



Solvent Absorption

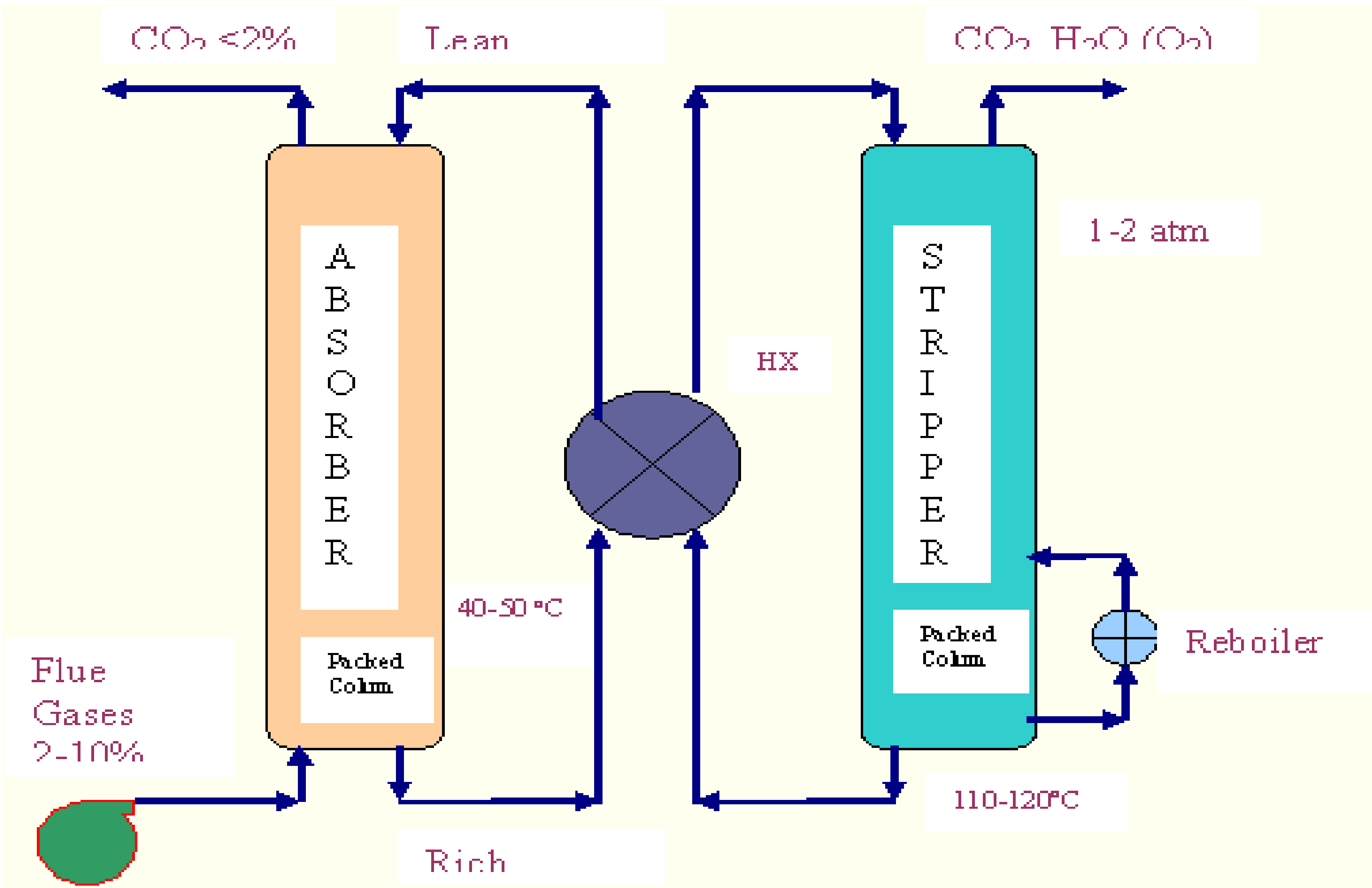
- CO_2 is soluble in some solvents:
  - Notably ethanolamines, e.g., monoethanolamine (MEA)

- Absorption proceeds at low temperatures, whereas desorption occurs at elevated temperatures:

$$C_2H_4OHNH_2 + H_2O + CO_2 \rightleftarrows C_2H_4OHNH_3^+ + HCO_3^-$$

- Solvent absorption has been used for decades for producing CO_2 from flue gas.
- The thermal efficiency of a coal gasification combined cycle power plant with CO2 capture by MEA is 30-35% compared to 40-45% without capture, and the cost increment of electricity production is around 50%.
- Thus, this method is less efficient and costlier than estimated for air separation CO2 recycling.
- But, this technology is well established.

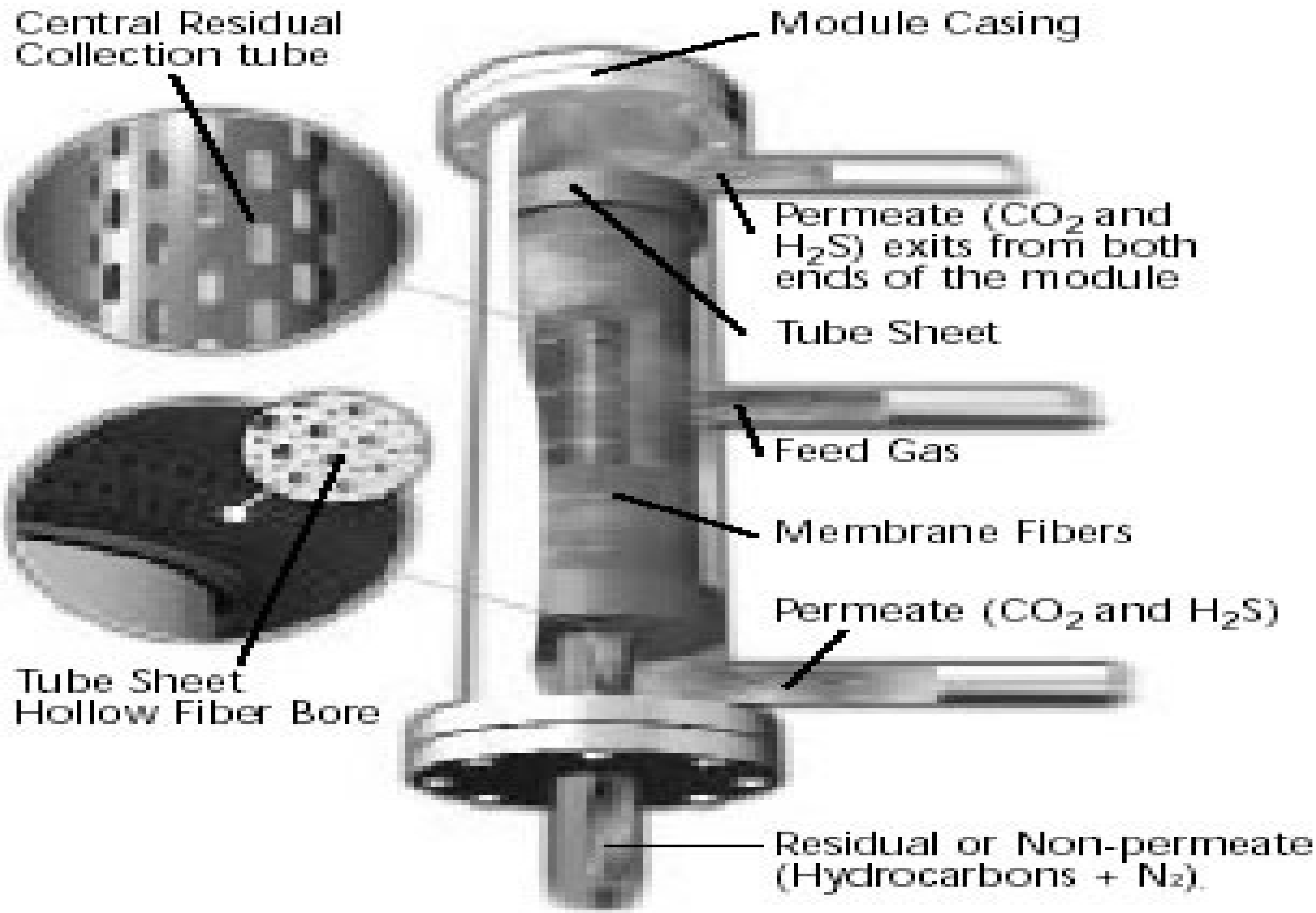
Solvent Absorption



Membrane Separation

- Gas separation by membranes relies on the different permeation rates of gases through the membrane pores.
- Typical membrane examples: *polysulfone/silicon, cellulose acetate, polyphenyleneoxide, polyalkene, polyimide, polydimethylsiloxane, and polytherimide*.
- The membrane method:
  - Capturing CO2 from a mixture of CO2 and H2, which is the product of coal gasification and the water shift reaction.

Membrane Separation

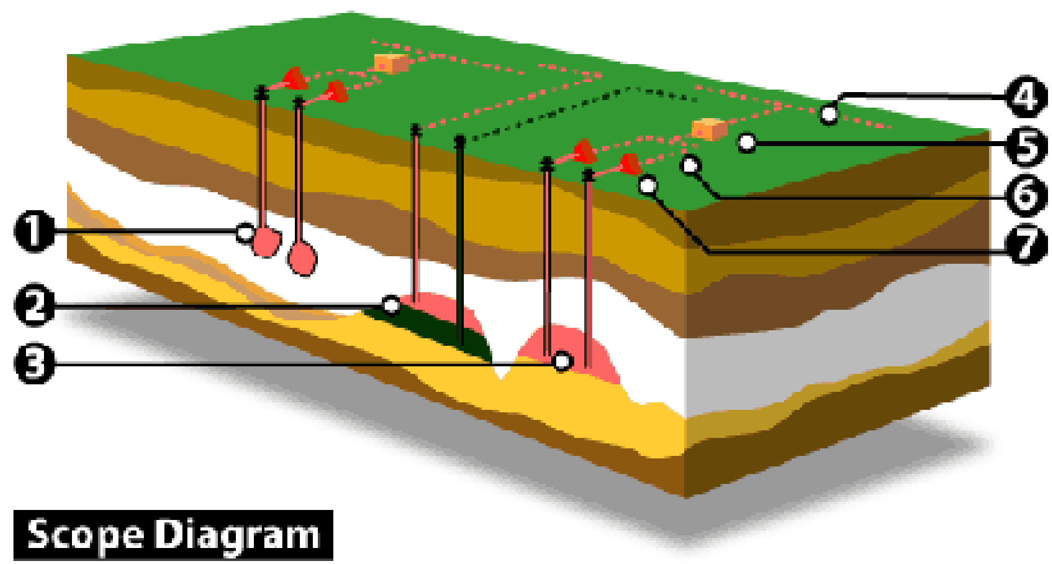


CO_2 Sequestration

- After capture, CO2 needs to be sequestered in a reservoir for an indefinite period.
- The following reservoirs are being investigated for sequestering CO_2:
  - Depleted oil and gas reservoirs
  - Deep ocean
  - Deep aquifers

Depleted Oil and Gas Reservoir

- In respect to sequestering CO_2, oil and gas reservoirs behave differently.
- CO_2 can be injected in to oil reservoirs while the oil is being pumped out of it.
- CO2 can be injected into gas reservoirs only after depletion of gas.
- The transport cost of piping supercritical CO2 is significant ***($2 to 7$ per metric ton of CO2 per 250 km distance).***



Scope Diagram

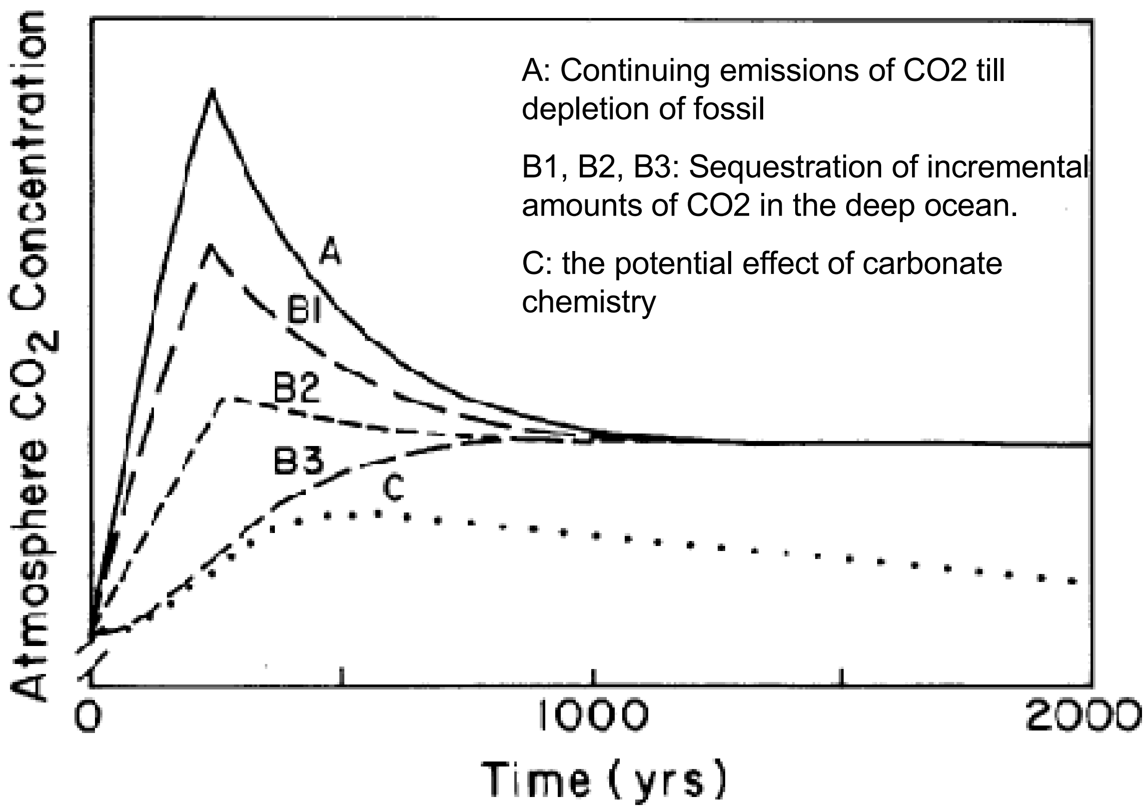
1. Salt cavern hydrocarbon storage
2. Oil & gas reservoir
3. Natural gas reservoir storage
4. Transmission pipeline
5. Compressor
6. Gathering pipeline
7. Emergency shut down valve

Deep Ocean

- The ocean is a natural repository for CO_2.
- There is a continuous exchange of CO_2 between the atmosphere and the ocean.
- The ocean absorbs about 92 Gt y^{-1} of carbon from the atmosphere, while it outgasses into the atmosphere about 90 Gt y^{-1}.
- Most of the ocean-atmosphere carbon exchange occurs within the surface layer of the ocean, about 100 m deep.
- The deep layers of the ocean, 1000m or deeper, are highly unsaturated in regard to CO_2.

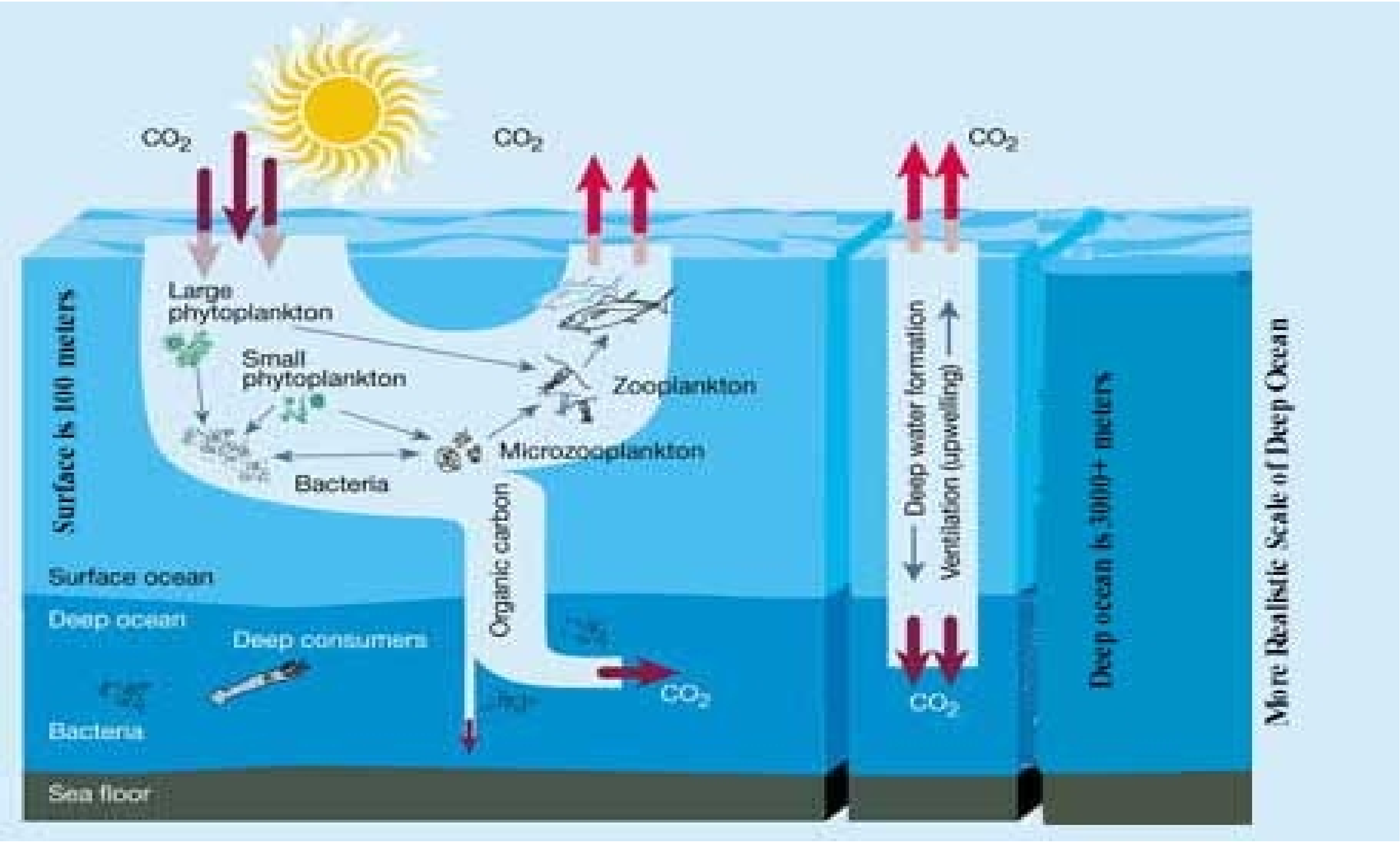
Deep Ocean

- The absorptive capacity of the deep ocean is estimated on order of E(19) tons of carbon.



Qualitative illustration of the effect of ocean sequestration on atmospheric concentrations of CO_2.

Deep Ocean



CO_2
CO_2
CO_2
Large phytoplankton
Small phytoplankton
Zooplankton
Microzooplankton
Bacteria
Organic carbon
Surface is 100 meters
Surface ocean
Deep ocean
Deep consumers
Bacteria
Sea floor
CO_2
Deep water formation
Ventilation (upwelling)
CO_2
Deep ocean is 3000+ meters
More Realistic Scale of Deep Ocean

Deep Ocean

- If injected at 500m or less, liquid CO2 would immediately flash into gaseous CO2 and bubble up to the surface.
- Between 500m and 300m the liquid CO2 injected from a diffuser at the end of a pipe would disintegrate into droplets of various diameters, depending on hydrostatic pressure of the liquid CO2 and the release orifice's diameter.
- >3000m, liquid CO2 becomes denser than seawater.
- The cost of such pipelines is estimated between $1 and 2$ million per kilometer length.

Deep Aquifers

• Aquifers are found at depths of 800 m or deeper.

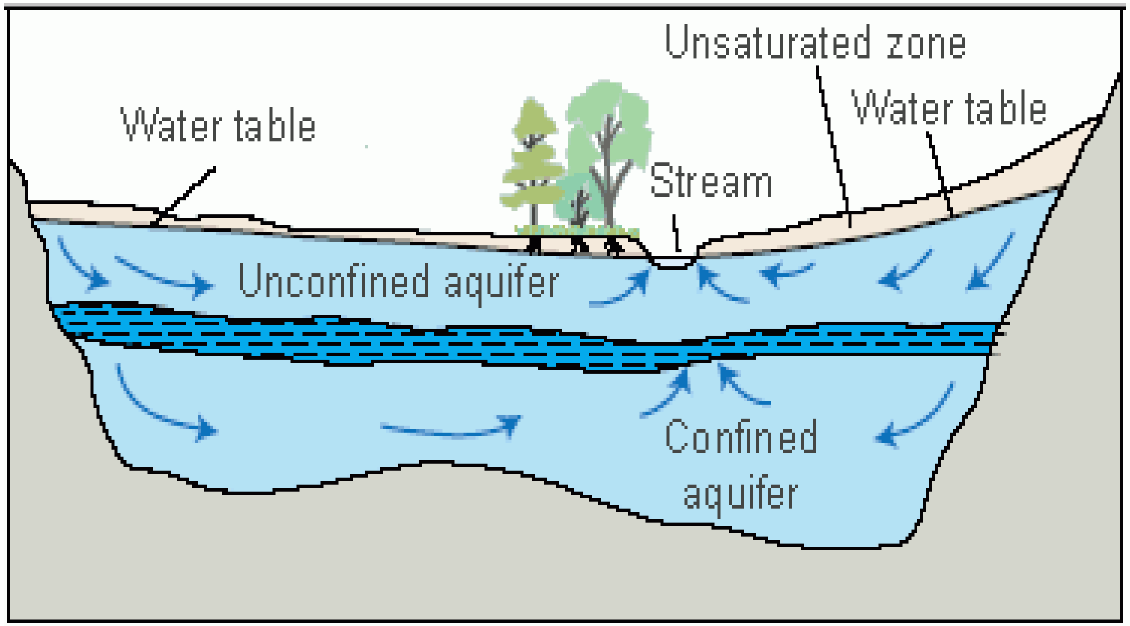
• The injected CO2 would dissolve in the brine as carbonic acid.

• The problem with deep aquifers:

✓not much their capacity

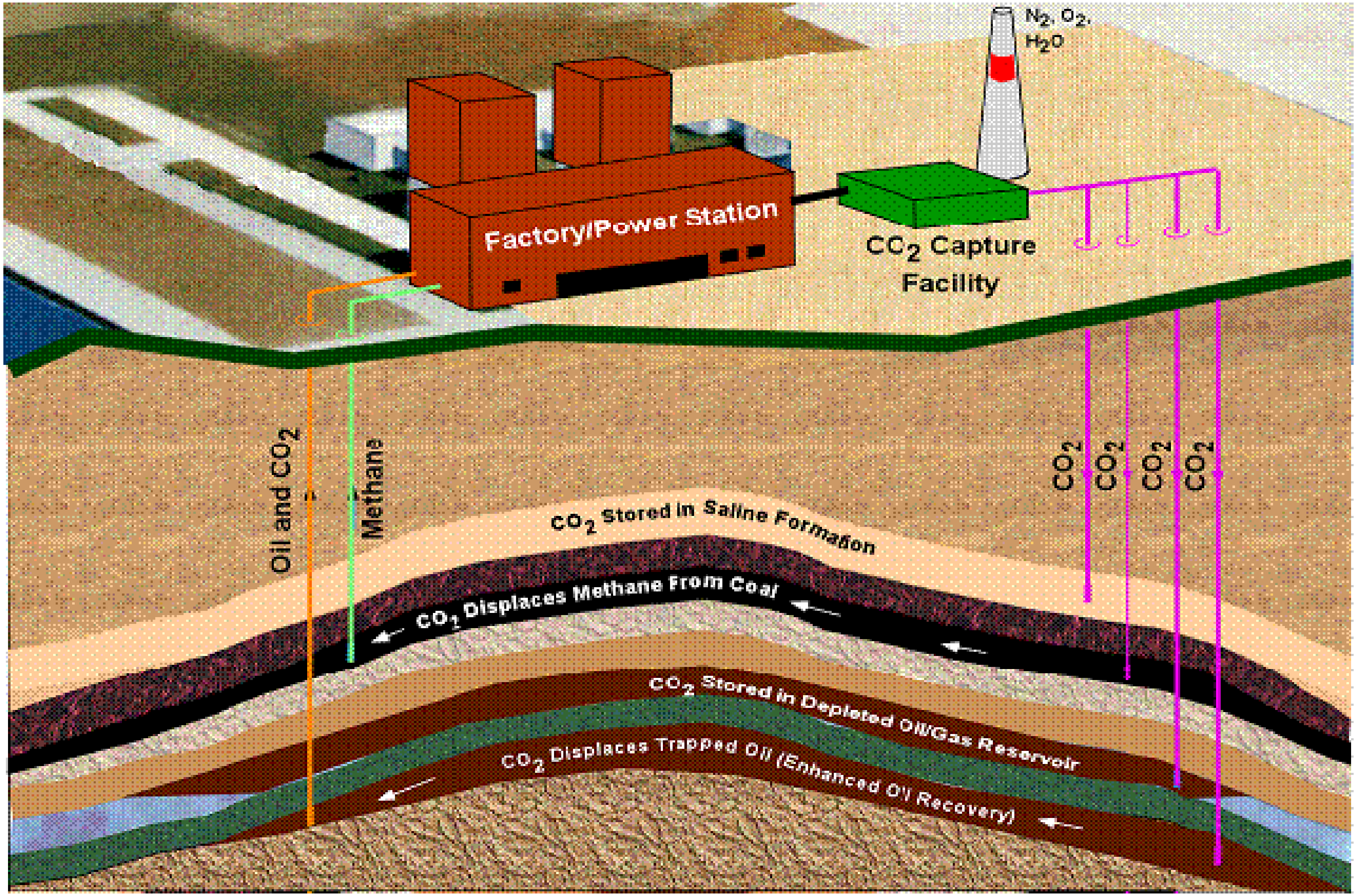
✓ the difficulty of drilling large diameter pipes, and constructing

✓ appropriate diffuser at the end of the pipe.



• ***Intensive research is ongoing to establishing the location and capacity of the deep aquifers for potential of CO_2 in them.***

Geologic Storage



CO_2 Utilization

- The use of flue gas CO2 for enhanced oil or gas recovery.
- For dry ice manufacturing, for carbonated drinks, a raw material for chemical products, methanol, or other oxygenated fuels.
- The problem with such propositions is twofold:
  - Most of the carbon in the product would eventually burn up or decompose back to CO2 and would wind up in the atmosphere.
  - The reduction of CO2 into the useful product requires virtually the same amount of energy as was given off when carbon oxidized into CO_2.

CO_2 Utilization

- Example of converting CO_2 to methanol:

$$CO_2(g)+3H_2(g) \rightarrow CH_3OH(l) + H_2O(l) \ -171 \ kJmol^{-1}$$

-the minus sign indicates that energy is leverated. However, three moles H2 require 858 kJ!

- Another example is the production of urea from CO_2:

$$CO_2(g)+3H_2(g)+N_2(g) \rightarrow NH_2CONH_2(s)+H_2O(l)+632kJ \ mol^{-1}$$

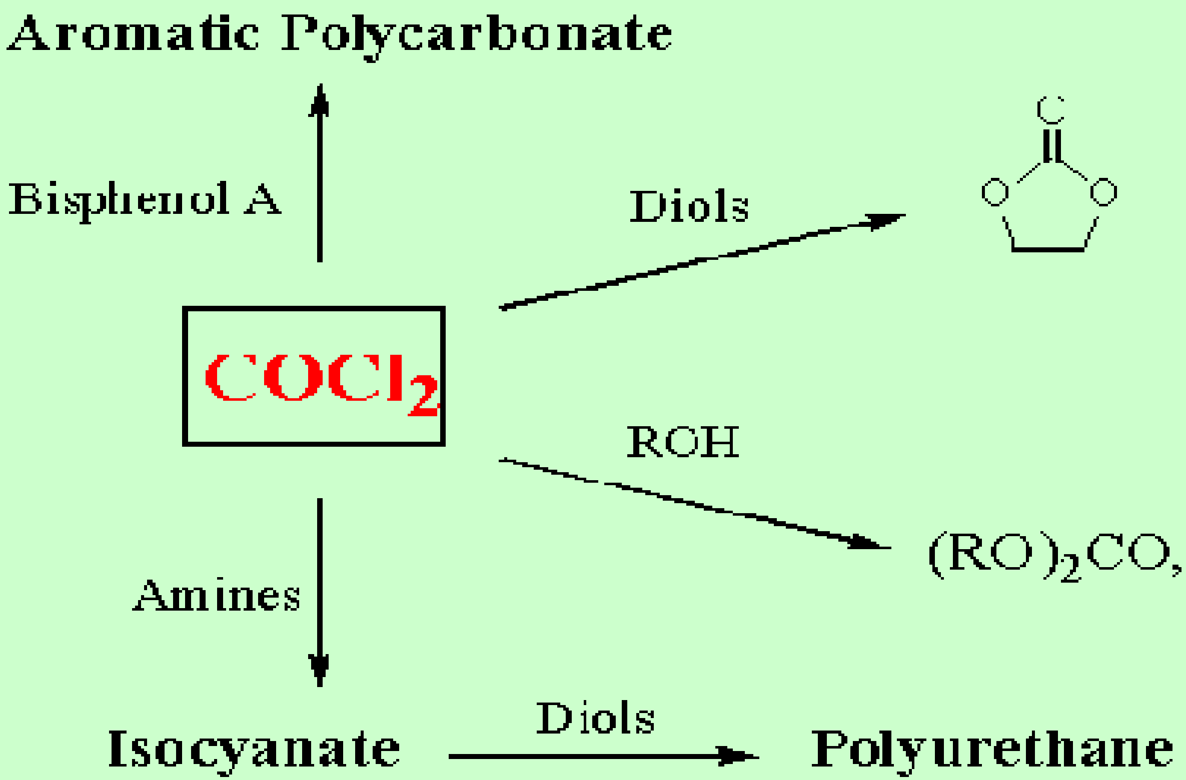
- This reaction is highly endothermic.

- For producing biomass by means of photosynthesis:

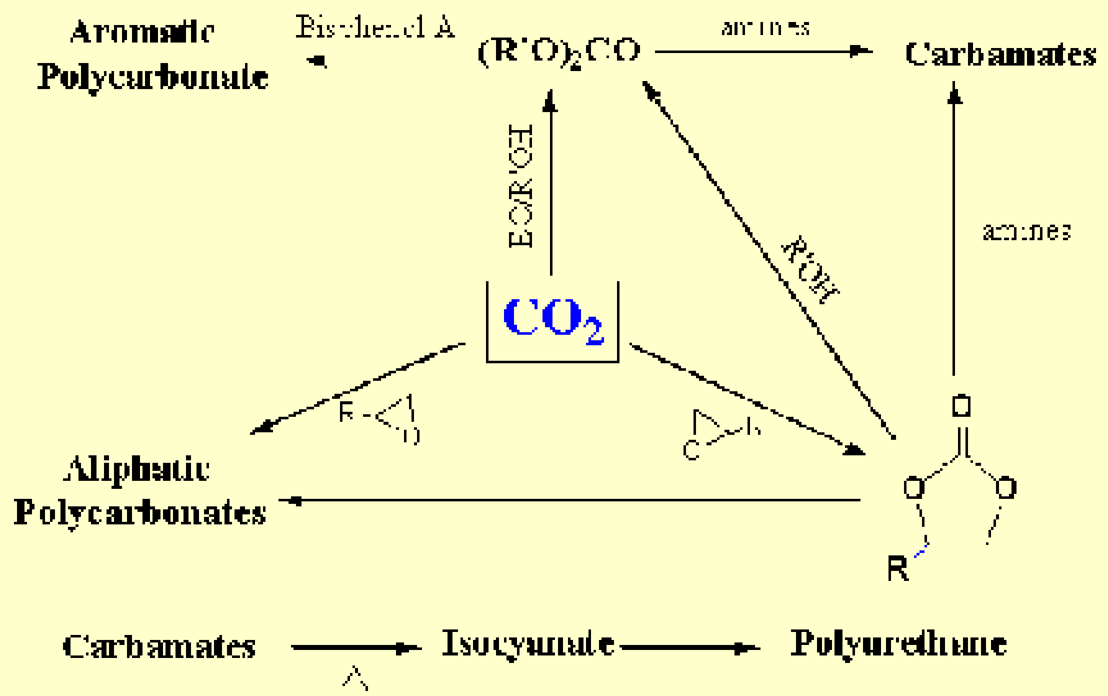
$$nCO_2+mH_2O \xrightarrow{h\nu} C_n(H2O)_m+O_2+570.5kJmol^{-1}$$

- Finally, one must note that deforestation has the opposite effect. Every hectare cleared of forests will reduce the absorption of CO2 by 6-10 t C $ha^{-1}y^{-1}$!

Phosgene Process



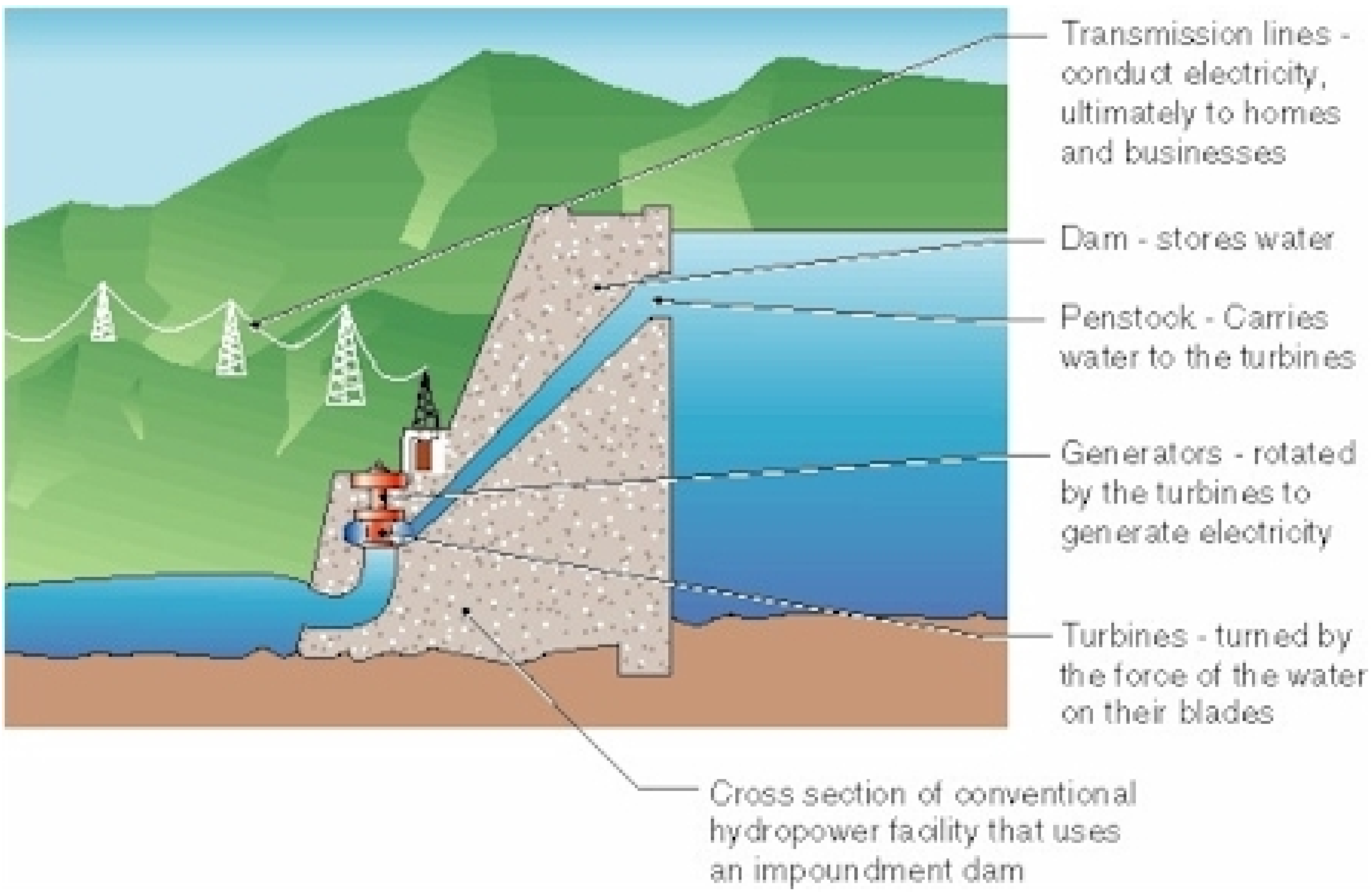
Non-phosgene Process using CO_2



Shift to Non-fossil Energy Sources

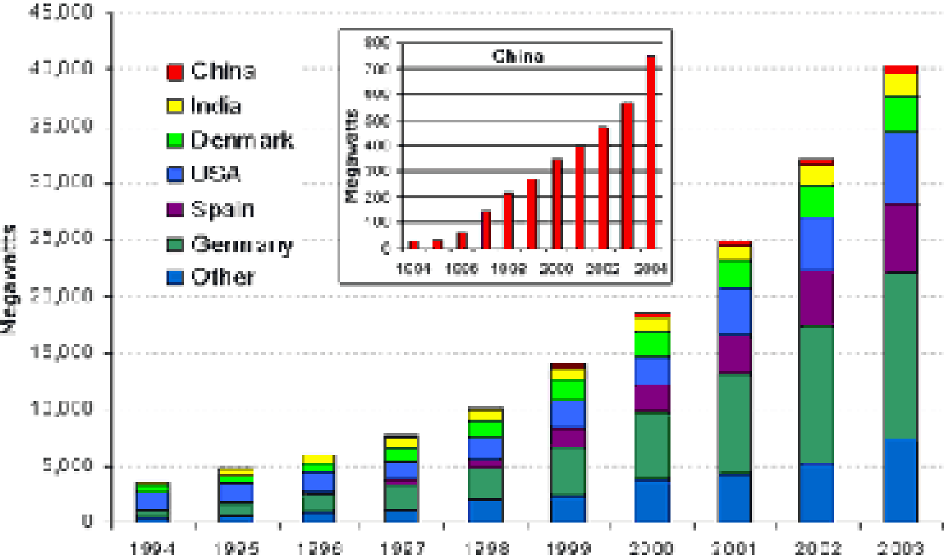
- Shift to noncarbon energy sources eliminates CO2 emissions completely.
- Except perhaps for fossil energy used in smelting steel and other construction materials used in the nonfossil energy conversion devices.
- Worldwide energy consumption:
  - 86% fossil
  - 6.5% nuclear
  - 7.5% renewables
- The only recourse would be a shift to renewables
- The renewables: ***hydroenergy, solar, wind, geothermal, and ocean energy***.

hydroenergy

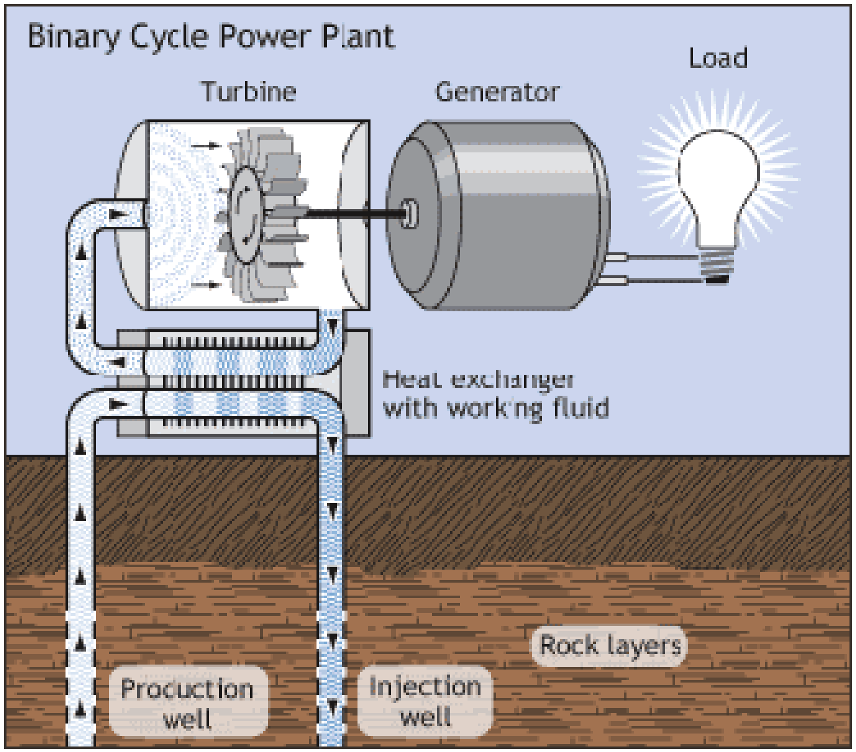


Solar energy

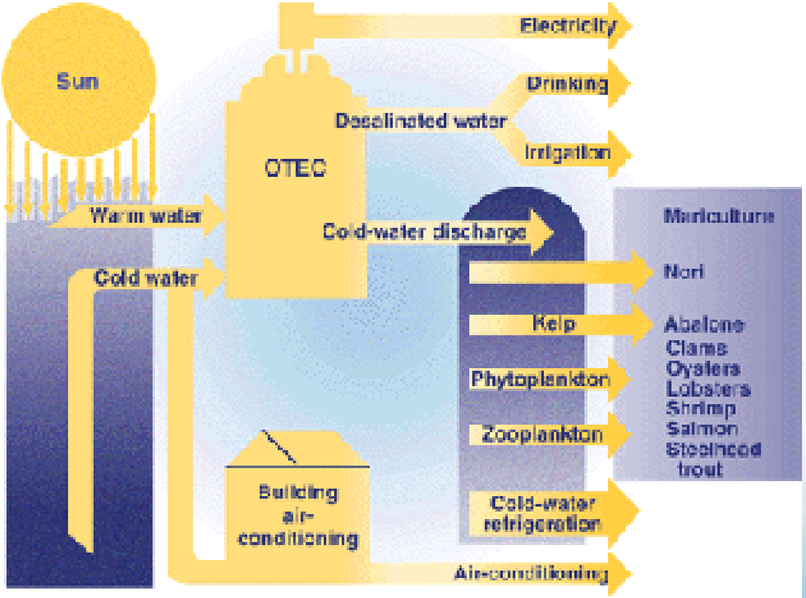
Wind Power


Megawatts
45,000
5,000
0
China
India
Denmark
USA
Spain
Germany
Other
China
Megawatts
1999

Geothermal Power



Ocean Power


Sun
OTEC
Electricity
Drinking
Desalinated water
Irrigation
Warm water
Cold water
Cold-water discharge
Mariculture
Nori
Kelp
Abalone
Clams
Oysters
Lobsters
Shrimp
Salmon
Steelhead trout
Phytoplankton
Zooplankton
Building air-conditioning
Cold-water refrigeration
Air-conditioning

Conclusion

- **Demand-side conservation and efficiency improvements.**
- **Supply-side efficiency measures.**
- **Capture of CO2 from the flue gas of power plants and sequestration in terrestrial or deep ocean reservoirs.**
- **Utilization of the captured CO_2.**
- **Shift to nonfossile energy sources.**
- **Greater use of biomass, especially wood.**
- **Stopping slash and burning practices of forests, especially tropical forests.**

Thank you!