Introduction to Solutions of Climate Change

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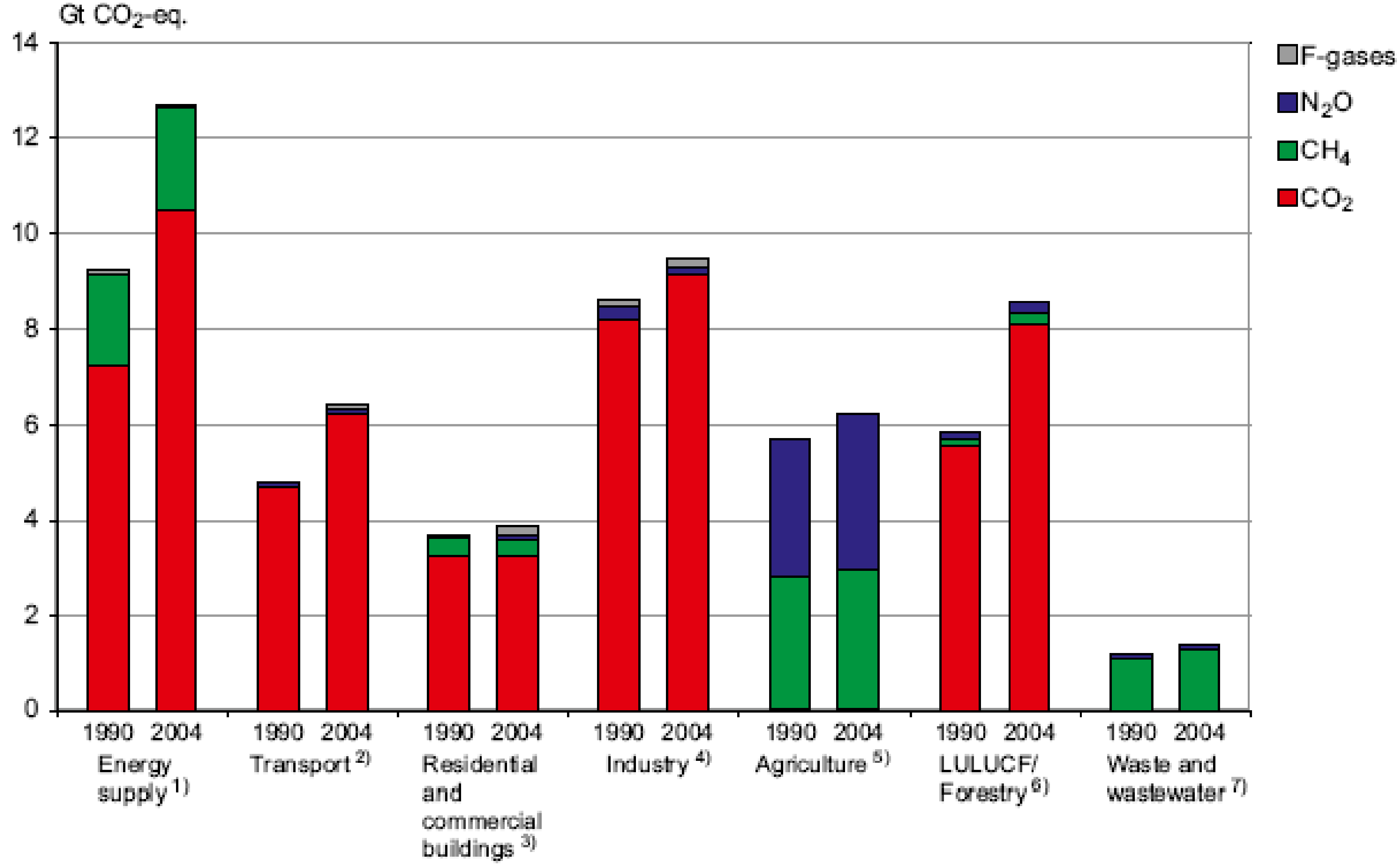
http://home.olemiss.edu/~cmchengs/Global%20Warming/Session%201%20Introduction%20-%20Part%201/

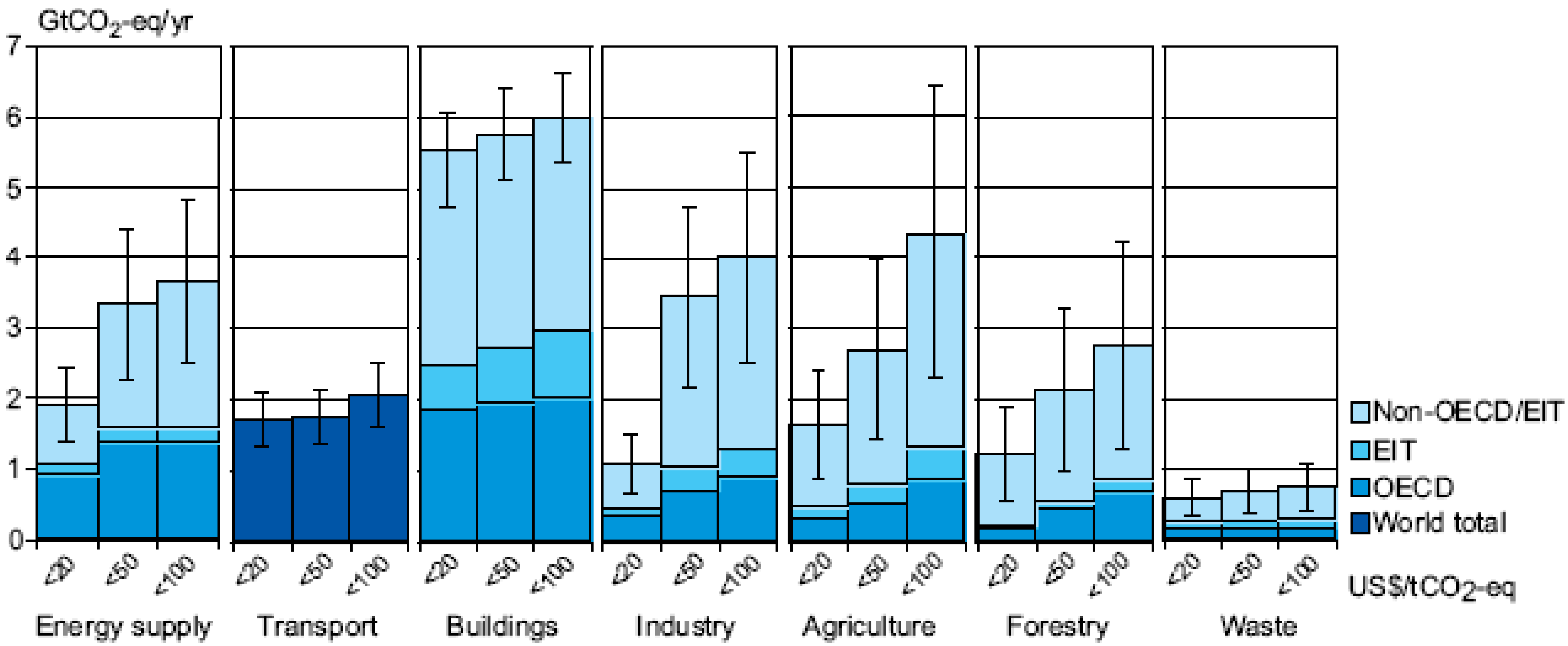
Solutions

- **Energy conservation and efficiency**
- **Alternative energy sources**
  - **Nuclear**
  - **Biofuels**
  - **Wind and Tide**
  - **Geothermal**
  - **Solar**
- **Advanced combustion and gasification technologies for efficient carbon utilization**
- **Advanced combustion enabling carbon capture and sequestration**
- **Advanced technologies**
  - **Photocatalytic reduction of CO_2**
  - **Electrochemical splitting H_2O**
- **Geoengineering**

GHG emissions by sectors in 1990 and 2004



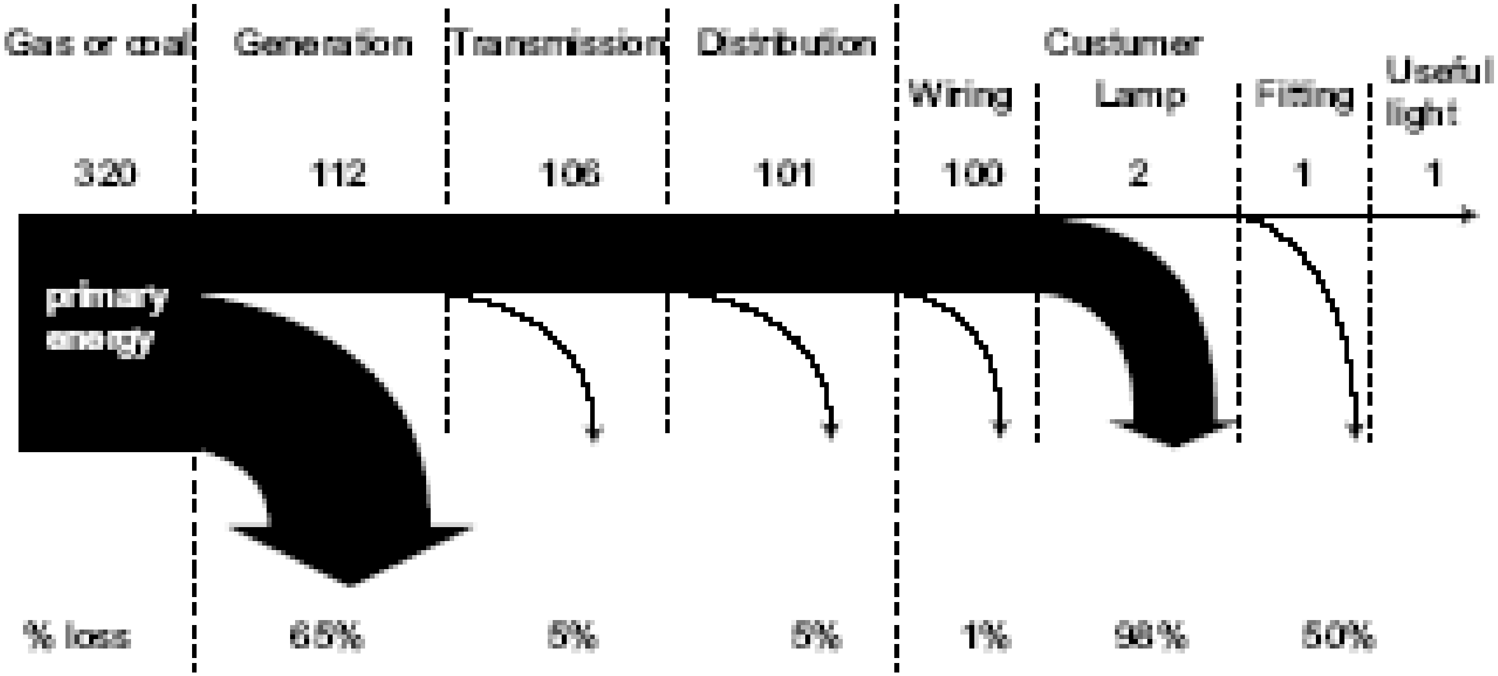
Estimated sectoral economical potential for global mitigation as a function of carbon price in 2030



(potential at <US$100/ tCO$_2$-eq: 2.4 - 4.7 Gt CO$_2$-eq/yr)	*(potential at <US$100/ tCO$_2$-eq: 1.6 - 2.5 Gt CO$_2$-eq/yr)*	*(potential at <US$100/ tCO$_2$-eq: 5.3 -6.7 Gt CO$_2$-eq/yr)*	*(potential at <US$100/ tCO$_2$-eq: 2.5 - 5.5 Gt CO$_2$-eq/yr)*	*(potential at <US$100/ tCO$_2$-eq: 2.3 -6.4 Gt CO$_2$-eq/yr)*	*(potential at <US$100/ tCO$_2$-eq: 1.3 - 4.2 Gt CO$_2$-eq/yr)*	*(potential at <US$100/ tCO$_2$-eq: 0.4 - 1 Gt CO$_2$-eq/yr)*

Conservation is extremely important, as 320 units of energy are needed in generating one unit of useful light.
Improving thermal efficiency and developing advanced carbon or non-carbon technologies are also viable.

a) Thermal-power energy and losses in the production of one unit of useful light energy.



Boiler efficiency
Carbon capture and sequestration
Advanced combustion for power generation
Non-carbon energy source – e.g., biofuels

Compact Fluorescent light (CFL) bulbs use 75% less energy than incandescent bulbs and last up to 10 times longer. That means you'll save money on energy costs while reducing your impact on the environment.

Table. Candidate technologies for CO_2 mitigation during power generation.

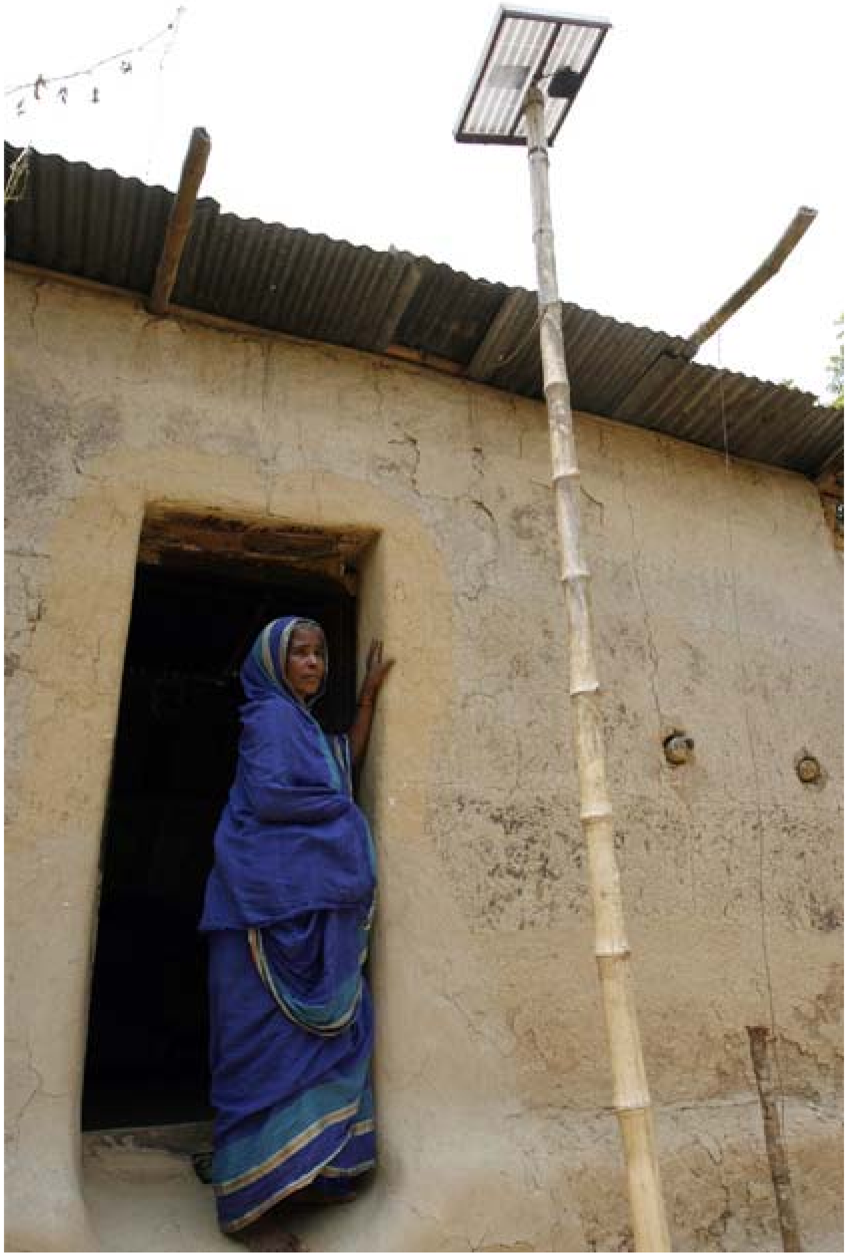
Technology	Current State of the Art	2050 Impact, Gt/yr *(6)*	Issues	RD&D Needs	Other Potential Environmental Impacts
Nuclear Power, Next Generation	Developmental, Generation III+ and IV: *e.g.*, pebble-bed modular reactor and supercritical-water-cooled reactor	1.9	Deployment targeted by 2030 with a focus on lower cost, minimal waste, enhanced safety, resistance to proliferation	High Demonstrations of key technologies with complementary research on important issues	Reduction in emissions SO_x, NO_x and fine PM; small but potent and long-lived waste could contaminate a small area
Nuclear Power, Current Generation	Commercial, Generation III: pressurized-water reactors and boiling-water reactors	1.8	Plant siting, high capital costs, levelized cost 10–40% higher than coal or gas plants, potential uranium shortages, safety, waste disposal, proliferation	Medium Waste disposal research	Reduction in emissions of SO_x, NO_x and fine PM; small but potent and long-lived waste could contaminate a small area
Natural Gas Combined Cycle	Commercial, 60% efficiency	1.6	Limited by natural gas availability (which is a major constraint), high efficiency, low capital costs	Medium Higher efficiencies, with new materials desirable	Reduction in emissions of SO_x, NO_x and fine PM; fewer mining impacts and residues for disposal or alternative uses
Wind Power (Renewable)	Commercial	1.3	Costs are very dependent on strength of wind source, large turbines are visually obtrusive, intermittent power source	Medium Higher efficiencies, onshore demonstrations	Reduction in emissions of SO_x, NO_x and fine PM; fewer mining impacts and residues for disposal or alternative uses; extraction R&D could enhance CH_4 availability
Coal IGCC with CCS	IGCC: Early commercialization UGS: Early development	1.3	IGCC: High capital costs, questionable for low-quality coals, complexity, potential reliability concerns; UGS: Cost, safety, efficacy	High IGCC: Demonstrations on a variety of coals , hot-gas cleanup research; UGS: Long-term demonstrations to evaluate many geological formations for efficacy, cost and safety	Lower power plant efficiency yields higher emissions of SO_x, NO_x and fine PM and higher coal mining impacts
Pulverized Coal/Oxygen Combustion with CCS	Developmental	1.3	Oxygen combustion allows lower-cost CO_2 scrubbing but oxygen production cost is high; UGS: Cost, safety and permanency	High Large-scale pilot tests followed by full-scale demonstrations, low-cost oxygen production; UGS: Long-term demonstrations to evaluate many geological formations for efficacy, cost and safety	Lower power plant efficiency yields higher emissions of SO_x, NO_x and fine PM and higher coal mining impacts

IGCC = Integrated Gasification Combined Cycle
CCS = CO_2 Capture and Storage
UGS = Underground Geological Storage
PM = Particulate Matter

Chem. Eng. Prog., Nov., 2007.

Solar Thermal Power (1/13)
View of a solar park under construction near Seville, Spain in May 2007. Large mirrors are used to concentrate the sun's rays onto the top of a 100-meter tower where it produces steam to drive a turbine. This project is part of a larger EU-financed Sanlucar la Mayor Solar Platform that, when completed in 2013, will produce enough energy to power 180,000 homes.

According to the UNEP, solar power received 16 percent of the overall 70.9 billion US dollars invested in renewable energy worldwide in 2006. (Photo: Reuters)



Photovoltaic (2/13)

A woman stands in the doorway of her mud house next to a photovoltaic panel in a village near Dhaka, Bangladesh. Photovoltaic solar panels directly produce electricity and help serve rural communities in developing countries. Only 30 per cent of Bangladesh's population has access to electricity grids. Most of the country's 140 million people still depend on kerosene and wood for their daily energy needs. (Photo: Reuters)

Wind Turbine (3/13)

An Australian homeowner adjusts a wind turbine on the roof of his house. Many homeowners are beginning to install small wind turbines on their property or roofs to offset their electricity bill and reduce their carbon footprint by relying less on conventional energy generation. Not all buildings or properties, however, are suitable for private, small-scale wind energy generation. (Photo: Reuters)

Wind Park (4/13)

An old windmill beside modern wind turbines near Magdeburg, Germany in August 2007. According to the Global Wind Energy Council, total installed wind energy capacity increased by 25 percent in 2006 making wind the third most important source for renewable power. Most of the world's 74 Megawatts of wind energy capacity are produced in Europe, but wind enegy is growing rapidly in North America and Asia. (Photo: Reuters)

Offshore Wind Park (5/13)

Wind turbines in the North Hoyle offshore wind park near Prestatyn, North Wales. Dozens of wind farms are up and running, with hundreds more planned as developers scramble to take advantage of Scotland's blustery climate and lucrative subsidies for renewable energy. Offshore wind parks could produce significantly more energy than onshore installations. Engineers, however, still struggle with rough conditions and high costs. (Photo: Reuters)

Biogas (6/13)

A worker adjusts a gas pipeline inside a biomass gasifier power plant in eastern Indian village of Gosaba serving about 1,200 local families with power.
Biomass refers to a variety of ways to convert organic matter into energy, often through combustion or the production of gases and liquid fuels. Biomass heat is the second most important source for renewable power. (Photo: Reuters)

Biomass and Biofuels (7/13)

Workers unload oil palms from a truck near Kuala Lumpur, Malaysia. Malaysian palm oil prices have surged due to rising demand for biodiesel. Palm oil is relatively cheap to convert to fuel, but environmentalists are concerned that much of the Malaysian and Indonesian rainforests will be destroyed to make way for palm oil plantations. (Photo: Reuters)

Hydrogen Fuel Cells (8/13)

Water vapor is emitted from a hydrogen-powered fuel cell bus in central London in January 2004. London is one of several cities to experiment with zero-emissions hydrogen fuel cell buses.

Hydrogen, the world's most abundant element has high energy content and low pollution. The typical byproduct of hydrogen fuel cells is water. Many companies experiment with such technology, but widespread application could be years or even decades away. (Photo: Reuters)

Hydroelectric Power (9/13)

The Cachi in Ujarras de Cartago hydroelectric dam in Costa Rica, a country committed to reducing its net greenhouse gas emissions to zero by 2030. Hydroelectric power is by far the most important source of renewable eneryg worldwide. But while it is cleaner than coal power generation in terms of carbon dioxide emissions, dams can also produce significant levels of methane emissions (another major greenhouse gas) and have a high environmental impact on local habitats and societies. (Photo: Reuters)

Wave Power (10/13)

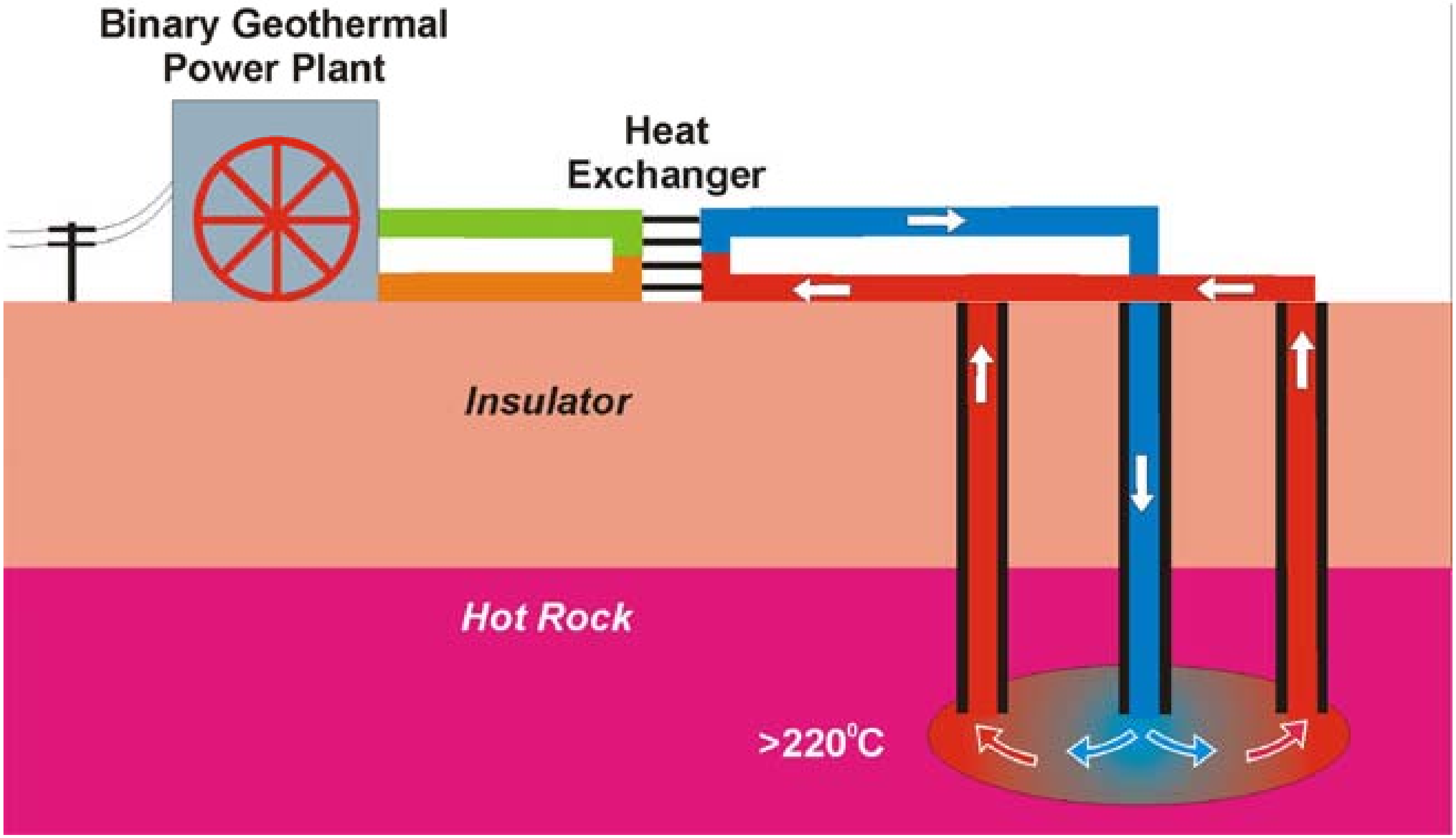
A model wave energy generator floating on the waters near Limfjorden, Denmark. A full-scale version of this prototype will be placed in the North Sea. It uses wave power to create electric energy. Earlier experiments with wave power, however, faced problems in rough seas. (Photo: Reuters)

Tidal Power (11/13)

The Rance tidal power plant uses the massive difference between low and high tide of the Atlantic. It is located on the estuary of the Rance River, in Bretagne, France. Special two-way turbines produce a maximum of 240 Megawatt (MW), about 4 percent of all energy consumed in the Bretagne. The plant, run by the French utility EDF, is the biggest in the world. A projected tidal power plant in South Korea could produce up to 250 MW. In most coastal areas, however, tidal power is not strong enough to efficiently produce energy. (Photo: EDF Médiathèque)

Geothermal Power (12/13)

The Blue Lagoon hot springs near Reykjavik, Iceland, with a thermal electricity plant in the background. Iceland uses its natural, hot, mineral-rich water caused by volcanic activity to power local industry and heat and provide electricity to most homes around Reykjavik. Geothermal power, however, is not strictly renewable as hot water cools down over time. (Photo: Reuters)

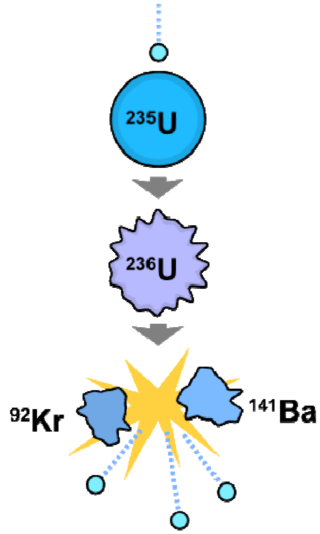


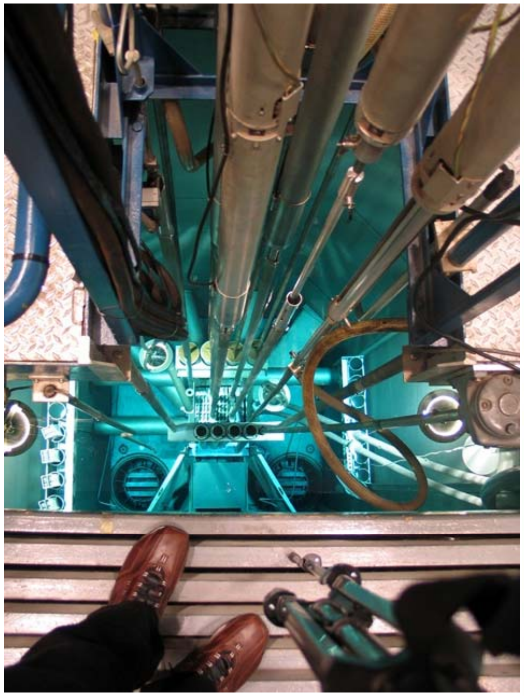
Geothermal II (13/13)

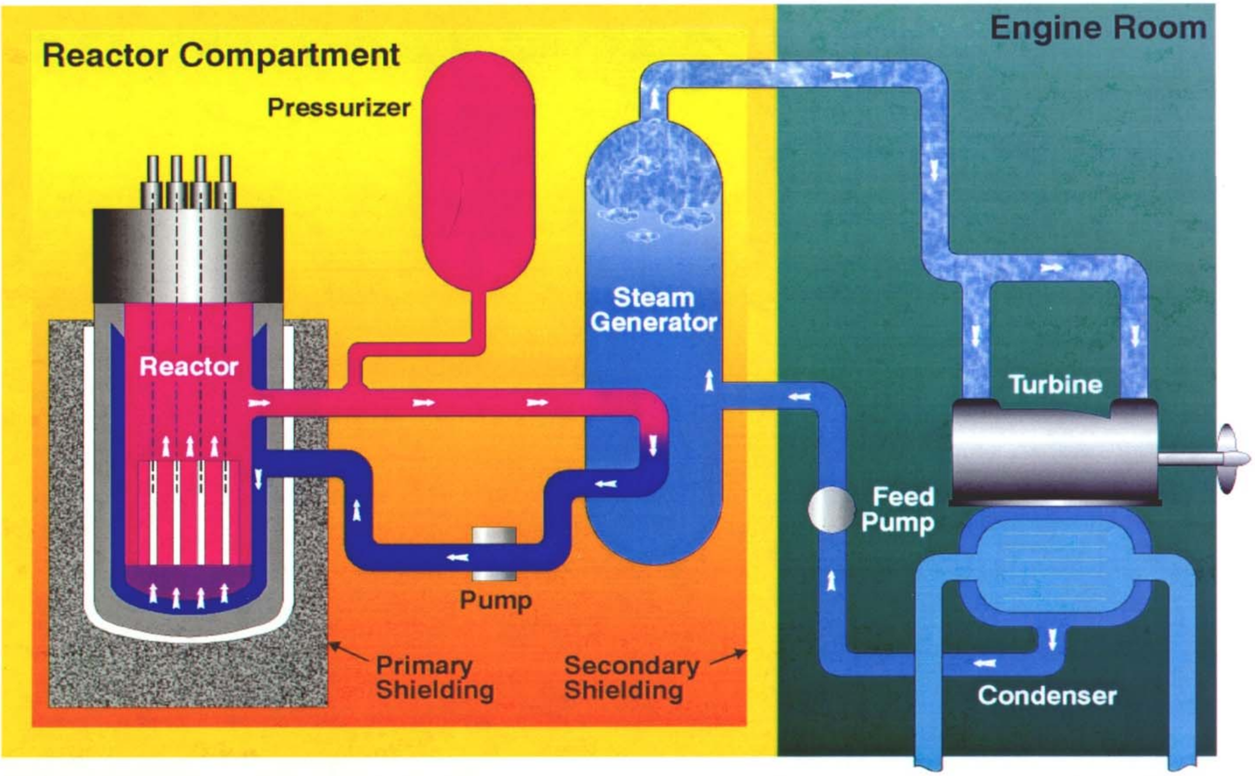
Not every country can rely on geothermal plants as a viable energy source. Engineers in Australia are trying to push the boundaries of geothermal energy usage by developing a new system to generate electricity from the heat of ancient rocks buried up to three kilometers below the Australian outback. Spurred by high commodity prices and a drive to reduce Australia's reliance on coal, several companies are looking to harness hot rock temperatures of up to 300 degrees Celsius (570 degrees Fahrenheit) to produce clean energy. (Graphic: Reuters)

Nuclear Power Plant

Fission is the splitting of atoms into smaller parts. Some atoms, themselves tiny, split when they are struck by even smaller particles, called neutrons. Each time this happens more neutrons come out of the split atom and strike other atoms. The plant controls the chain reaction to keep it from releasing too much energy too fast. In this way, the chain reaction can go on for a long time.





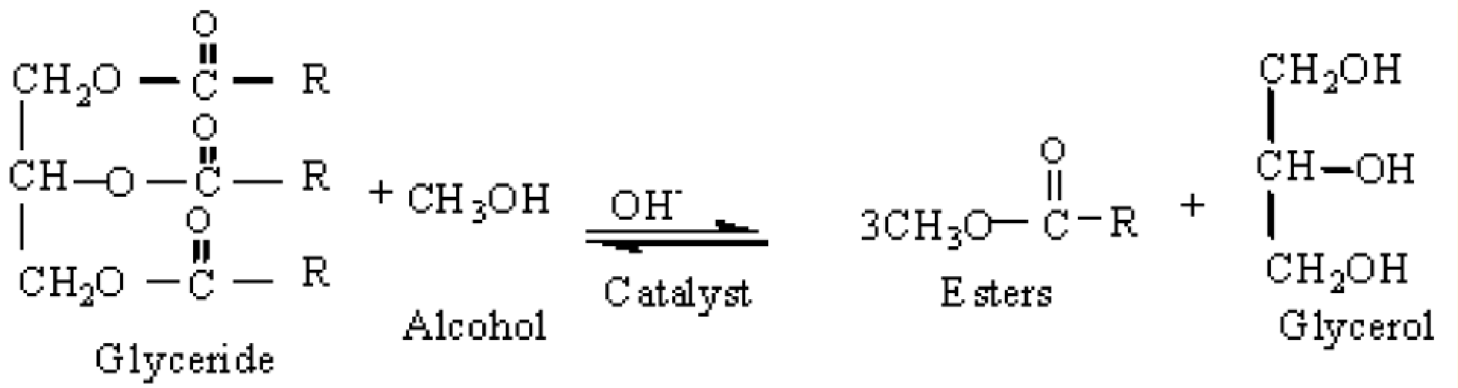


Types of Biofuels

- Biodiesel from vegetable oil and fat
- Corn and cane ethanol
- Cellulosic ethanol (Cell EtOH)
- Thermal conversion of biomass
- Others

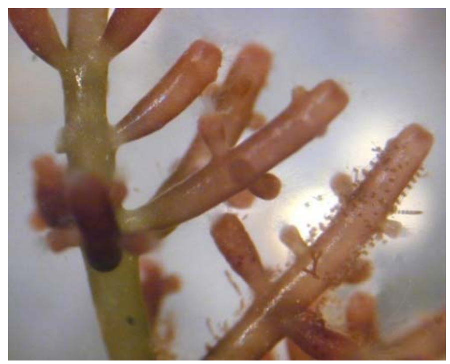
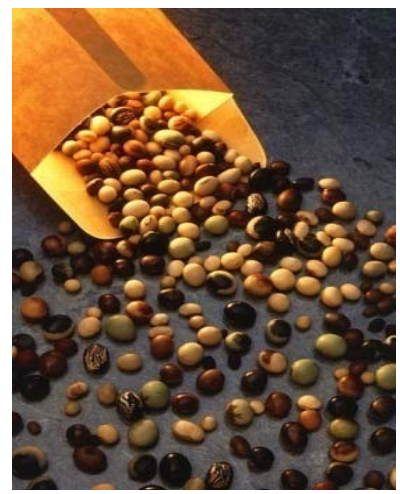
Biodiesel

- **Vegetable oil or animal fat reacted with an alcohol using a catalyst, usually a base (OH^-) by transesterification.**



- **Biodiesel is known chemically as a “fatty acid methyl ester.”**



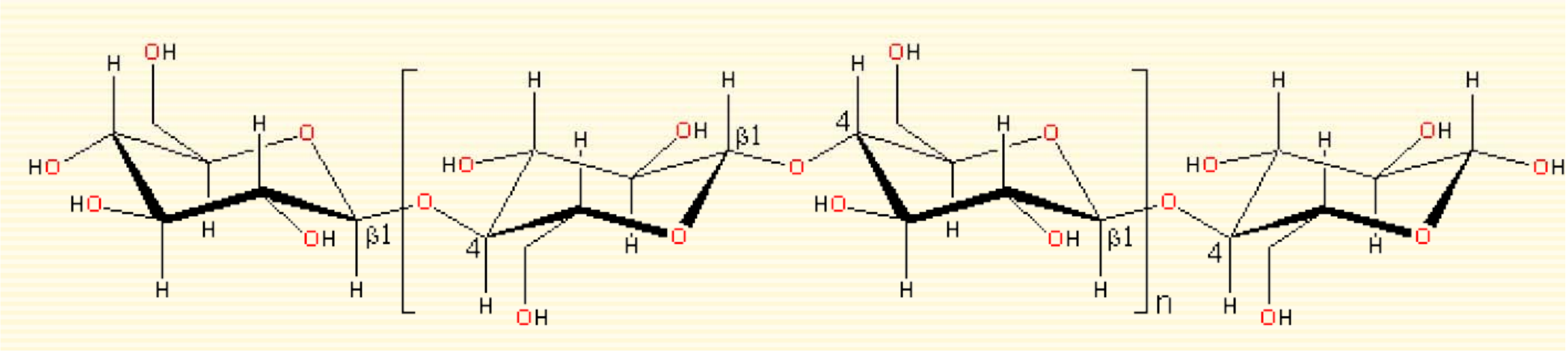
http://www.utahbiodieselsupply.com/biodieselbasics.php

Corn and Cane Ethanol

- Ethanol produced from hydrolysis of carbohydrates such as corn (starch) and from sugar cane followed by fermentation of sugar.
- Main products: EtOH, CO_2, high protein animal feed wet distillers grains with solubles or WDGS
- Corn is ground into coarse flour.
- Water and enzymes are added and the mixture “cooked.”
- Yeast is added, and the mixture fermented.
- The “mash” is distilled to recover the EtOH.

Cellulosic Ethanol

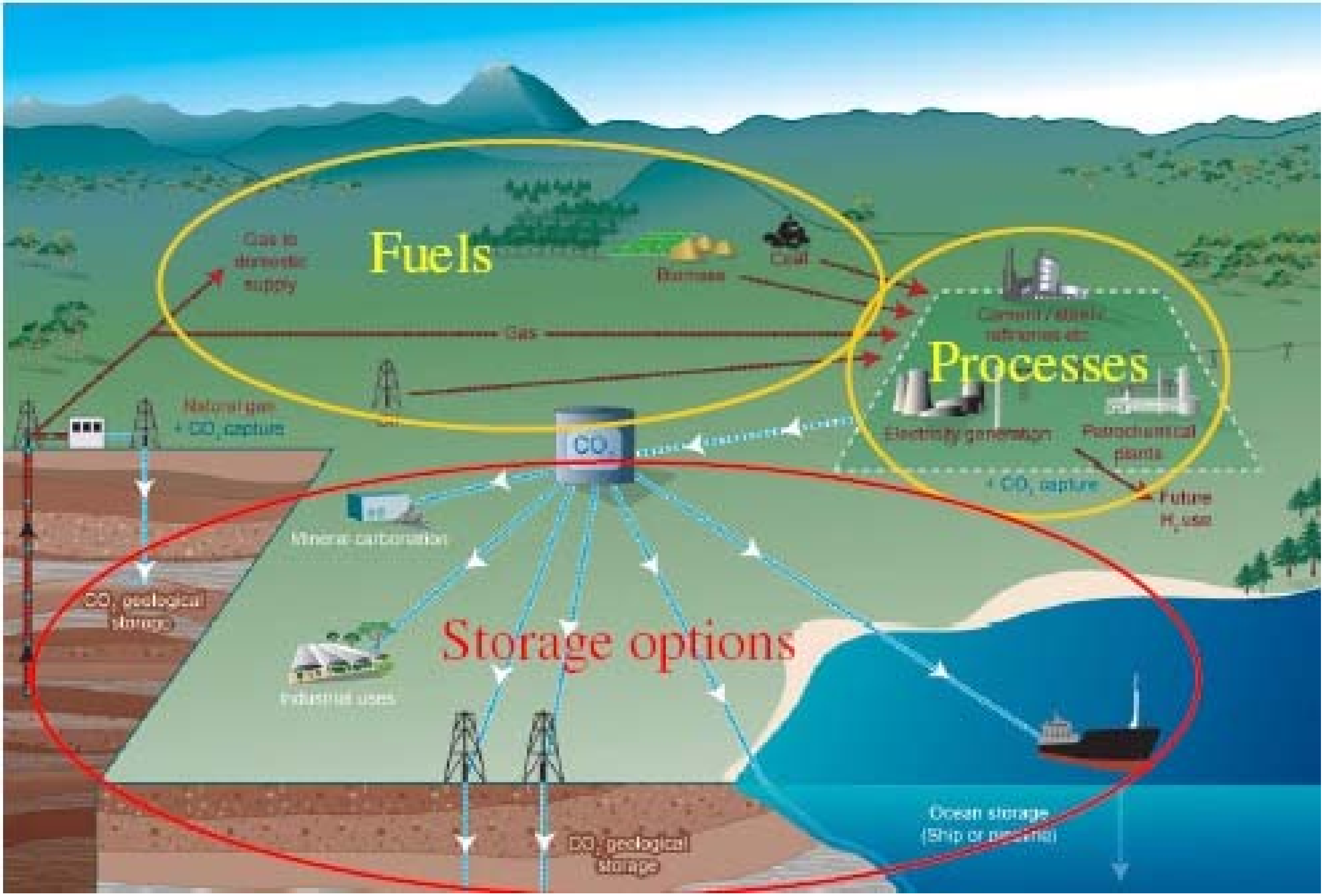
- Cellulose is first hydrolyzed by heated, diluted acid at high pressure or enzyme to glucose.
- The acid treatment or unrecoverable enzyme is a cost constraint in the process.
- Cellulose is a basic components of essentially all plants. Thus, if economically produced, cellulosic ethanol can relief food demand from cone ethanol.



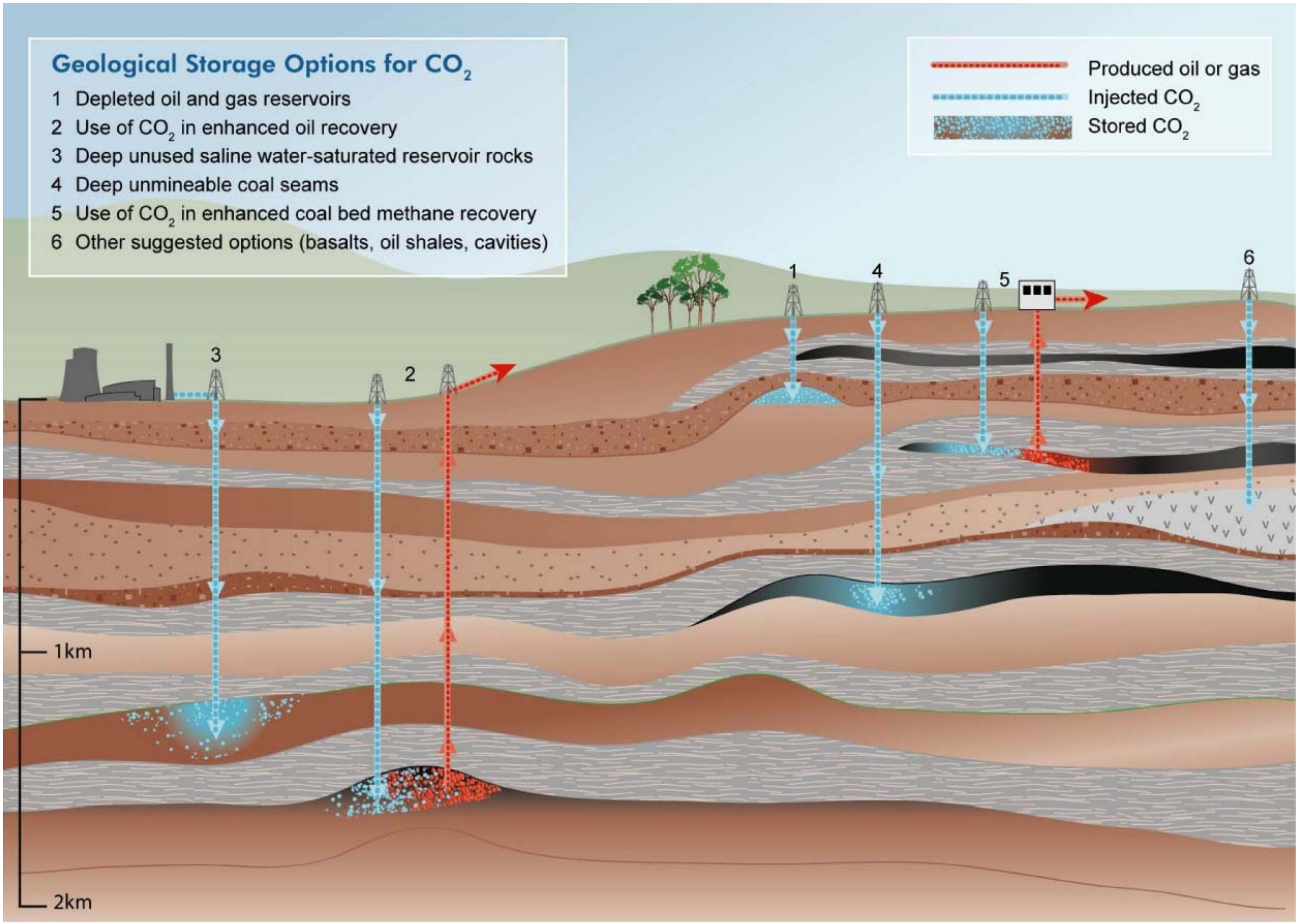
http://www.lsbu.ac.uk/water/hycel.html

Mitigating CO_2 Emissions by Advanced Coal Utilization

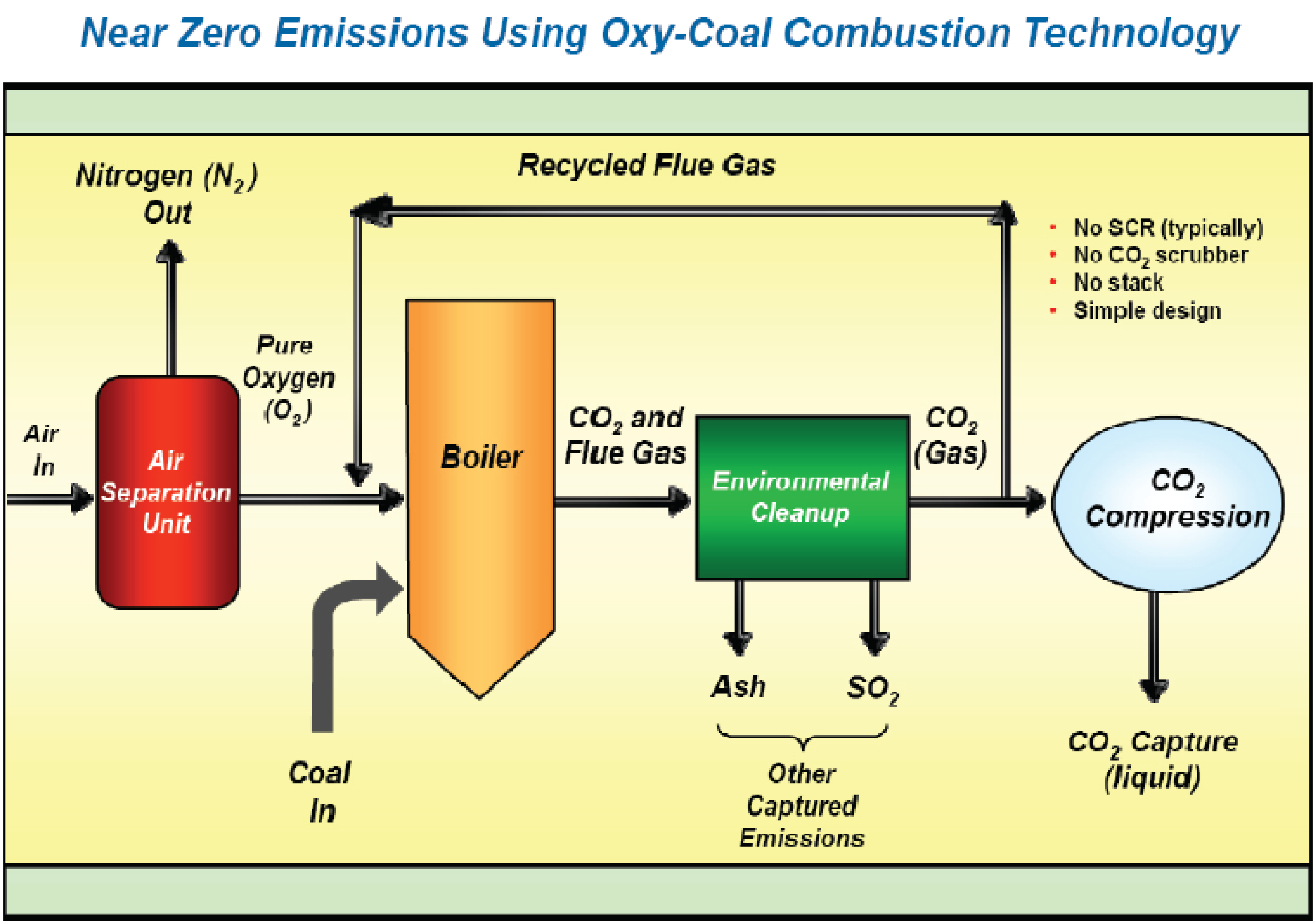
CO_2 capture and storage system



Geological Sequestration Options

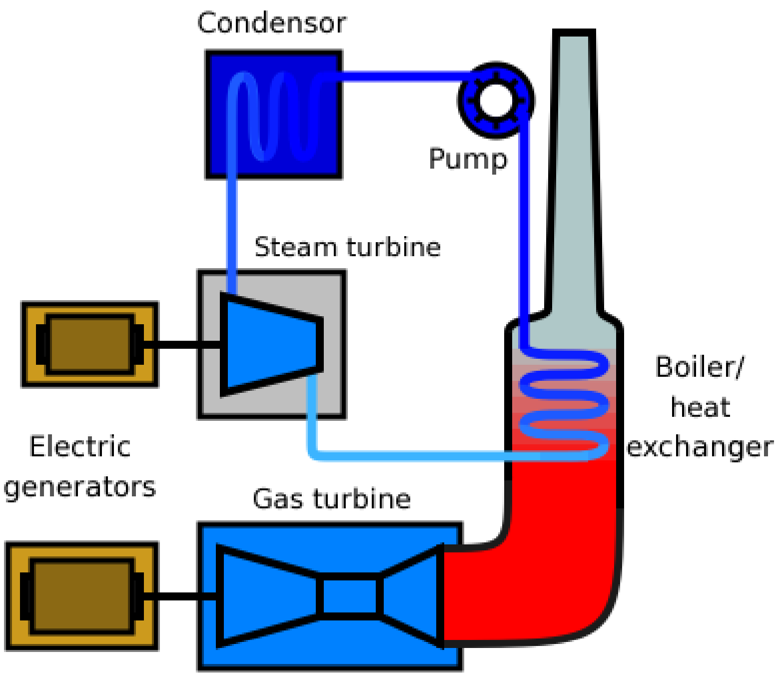


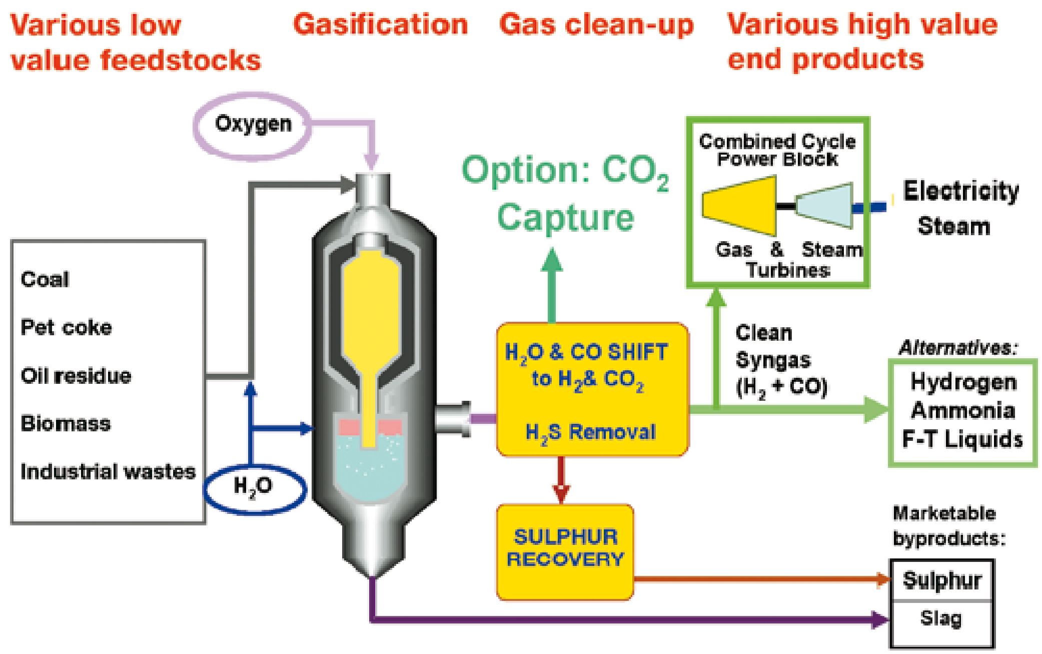
Oxy – Combustion



IGCC to Mitigate Global Warming

- **The combined cycle improves overall efficiency and therefore less CO_2 is produced per energy produced.**



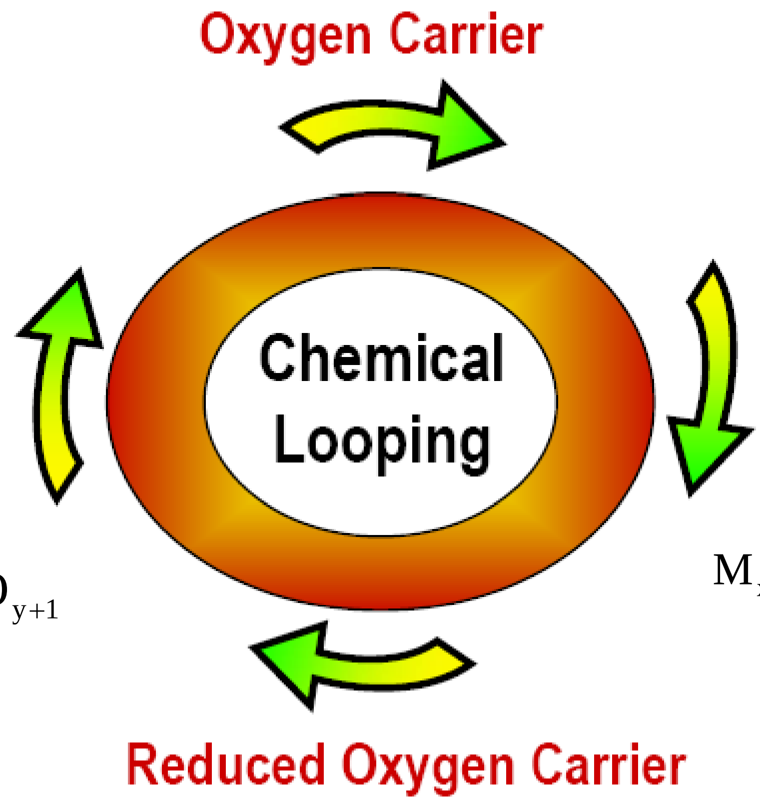


Chemical Looping Concept

Oxidation

The oxygen carrier removes oxygen from air and regenerates itself

$$M_xO_y + \frac{1}{2} O_2 \rightarrow M_xO_{y+1}$$

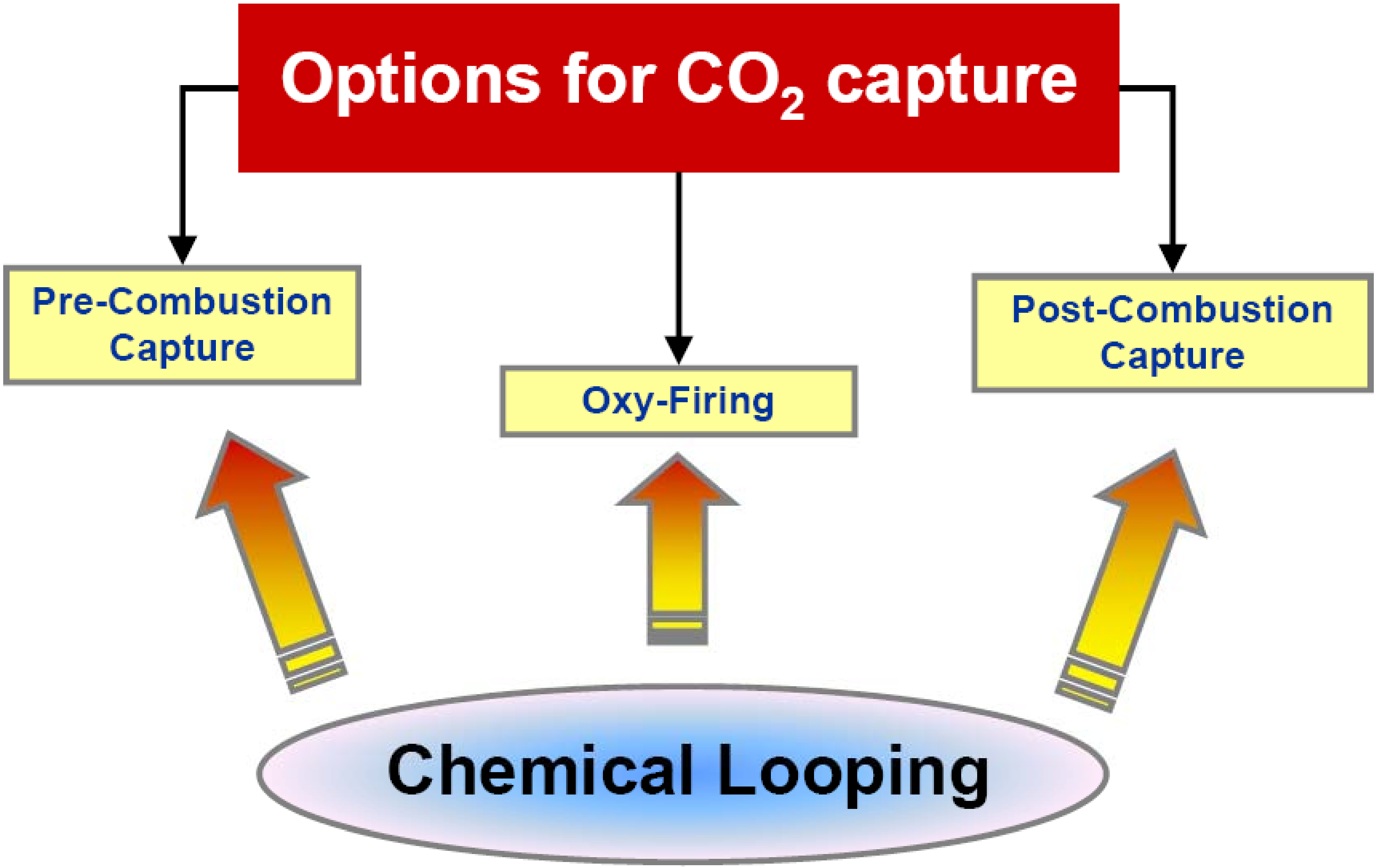


Reduction

The oxygen carrier provides oxygen to a reaction site

$$M_xO_{y+1} \rightarrow M_xO_{y-1} + \frac{1}{2} O_2$$

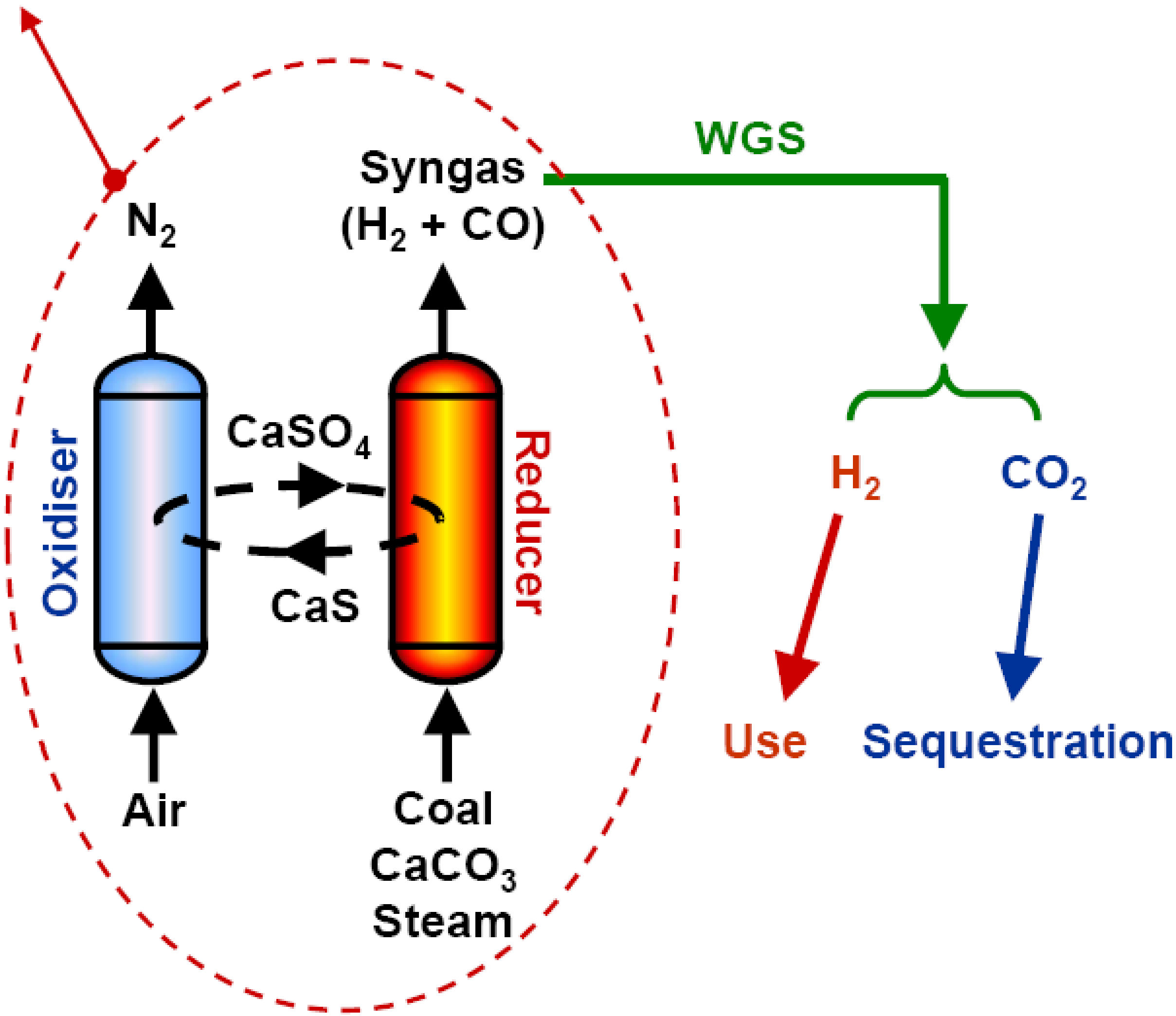
Chemical Looping



(1) Chemical looping as a pre-combustion capture technology

Chemical Looping Gasification

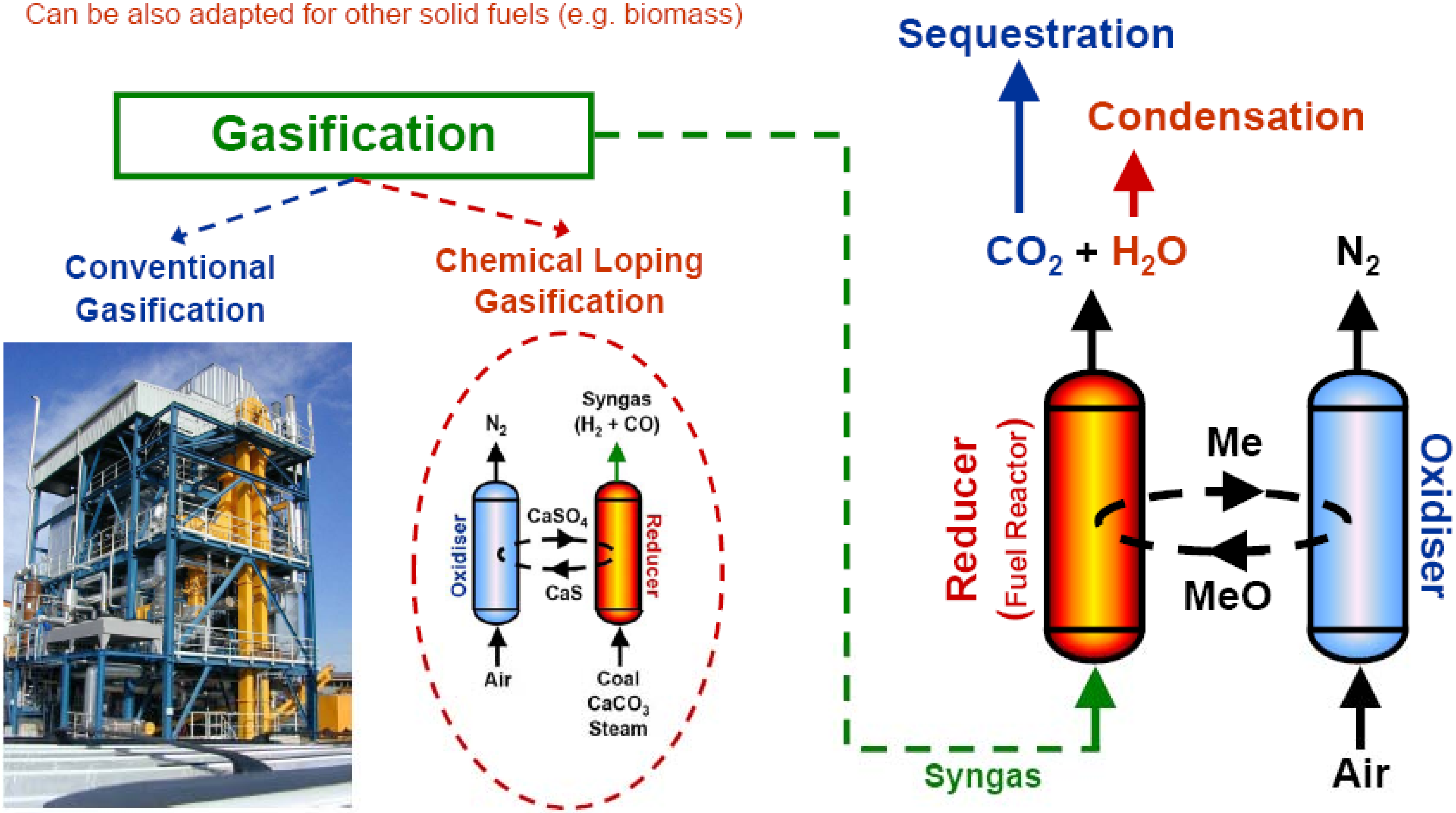
- Applicable to IGCC, and
- Fuel Cell cycles



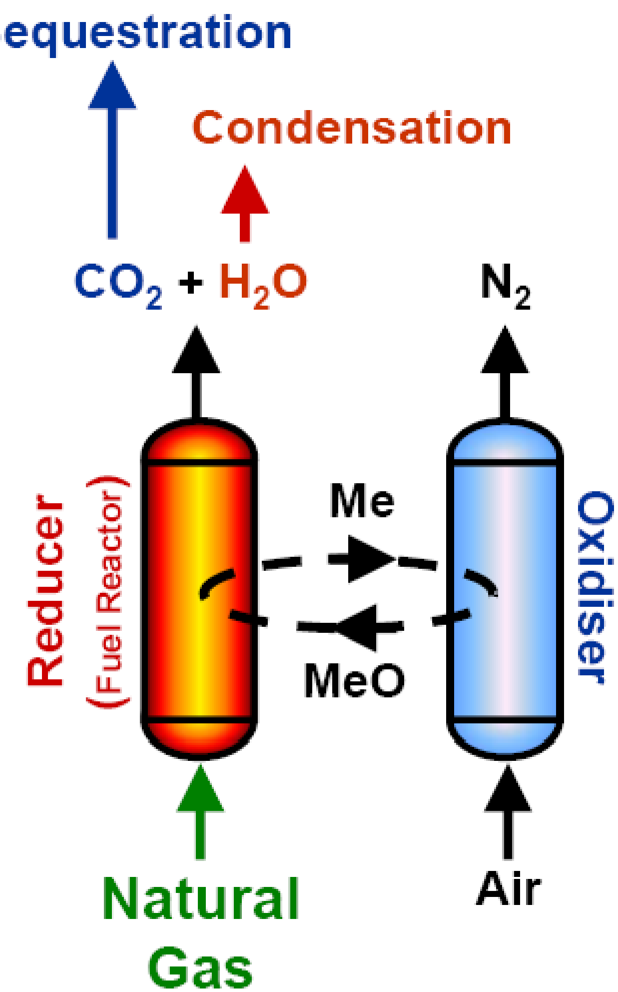
(2) Chemical looping as an oxy-firing technology

Chemical Looping Combustion (for Coal)

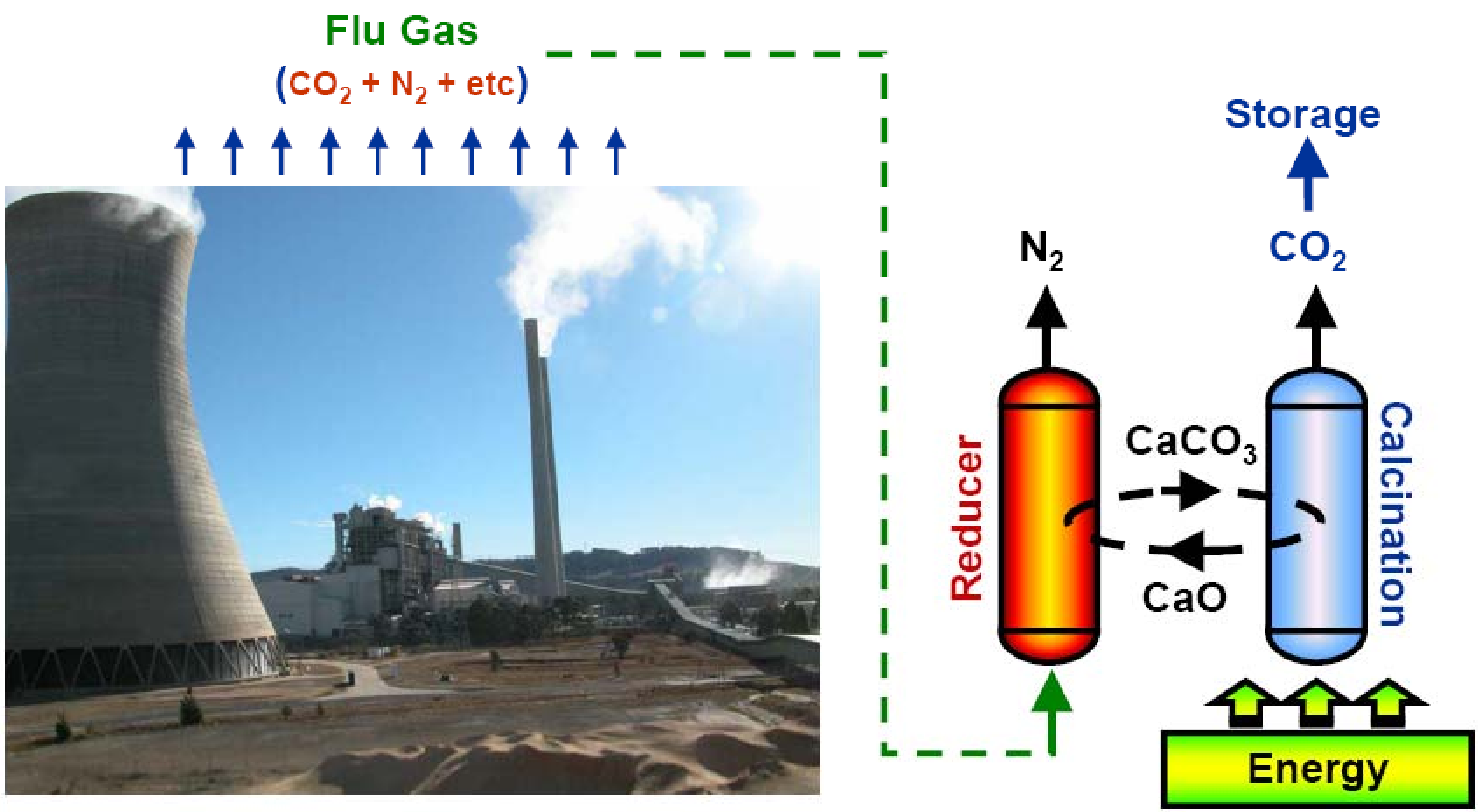
Can be also adapted for other solid fuels (e.g. biomass)



Chemical Looping Combustion (for gaseous fuels)



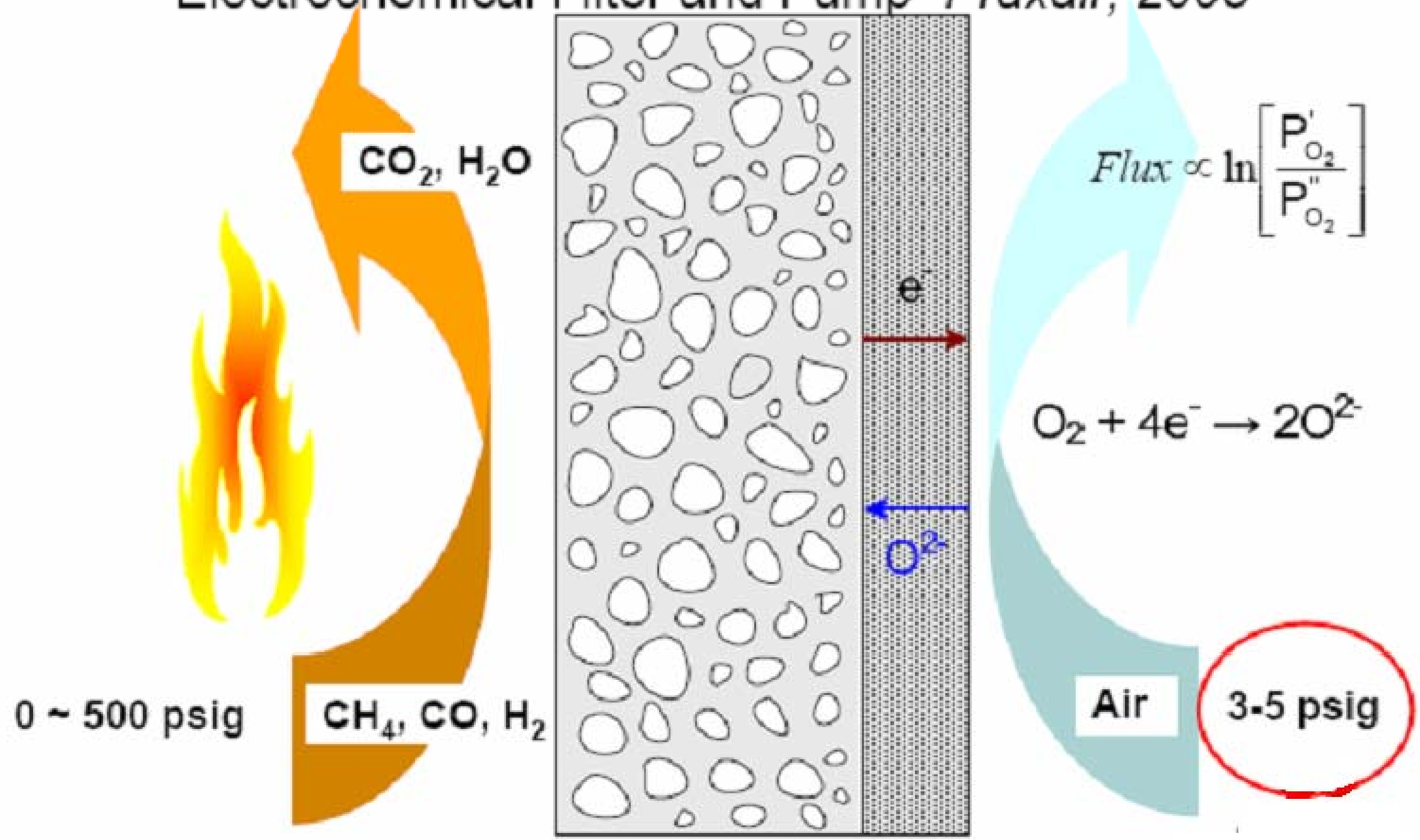
(3) Chemical looping as a post-combustion capture technology



Coal (or Gas) fired Power Plants

Example: Potential breakthrough: *Integrated* Oxygen Transport Membrane (OTM)

"Electrochemical Filter and Pump" *Praxair, 2005*



Basic Research Needs in Catalysis for Energy Workshop: August 6-9, 2007

Co-Chairs: **Alexis T. Bell (UC-Berkeley)**
Bruce C. Gates (UC-Davis)
Douglas Ray (PNNL)

Breakout Session Panel Leaders:

Gand Challenges in Catalysis
- Mark Barteau, U Delaware
- Dan Nocera, MIT

Conversion of Fossil Energy Feedstocks
- Marvin Johnson, Philips Petrol. – ret.
- Johannes Lercher, TU-Munich

Conversion of Biologically-Derived Feedstocks
- Harvey Blanch, UC-Berkeley
- George Huber, U Massachusetts

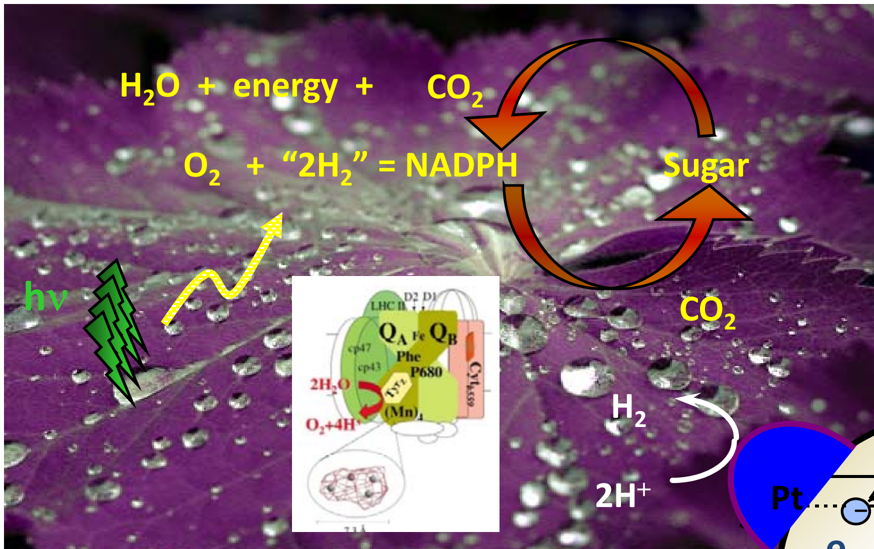
Photo- and Electrochemical Conversion of H_2O and CO_2
- Michael Henderson, PNNL
- Peter Stair, Northwestern U

Cross-Cutting Themes
- Jingguang Chen, U Delaware
- Bruce Garrett, PNNL

Charge: Identify the basic research needs and opportunities in catalytic chemistry and materials that underpin energy conversion or utilization, with a focus on new, emerging and scientifically challenging areas that have the potential to significantly impact science and technology. The workshop ought to uncover the principal technological barriers and the underlying scientific limitations associated with efficient processing of energy resources. Highlighted areas must include the major developments in chemistry, biochemistry, materials and associated disciplines for energy processing and will point to future directions to overcome the long-term grand challenges in catalysis.

BES shepherds: John Miller and Raul Miranda

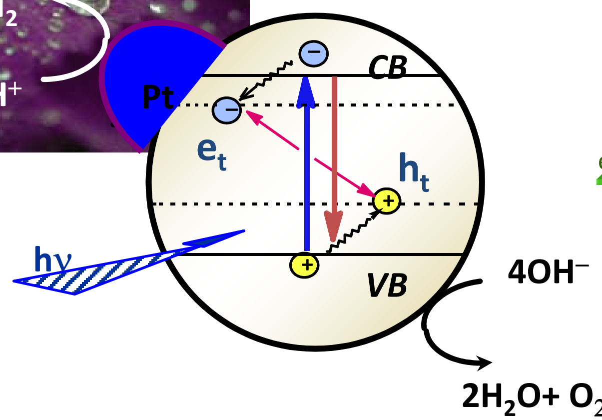
Advanced Catalysts for Photo- and Electro-Driven Conversion of H_2O and CO_2

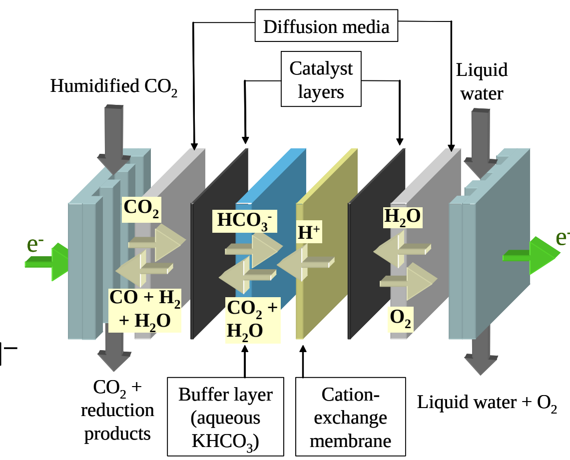


Plants use solar energy to convert H_2O and CO_2 to sugars with an energy efficiency of < 1%

Photo-electrocatalytic systems convert H_2O to H_2 with an energy efficiency of 1-10%

Electrochemical systems convert H_2O/CO_2 to H/CO with an energy efficiency of ~50%

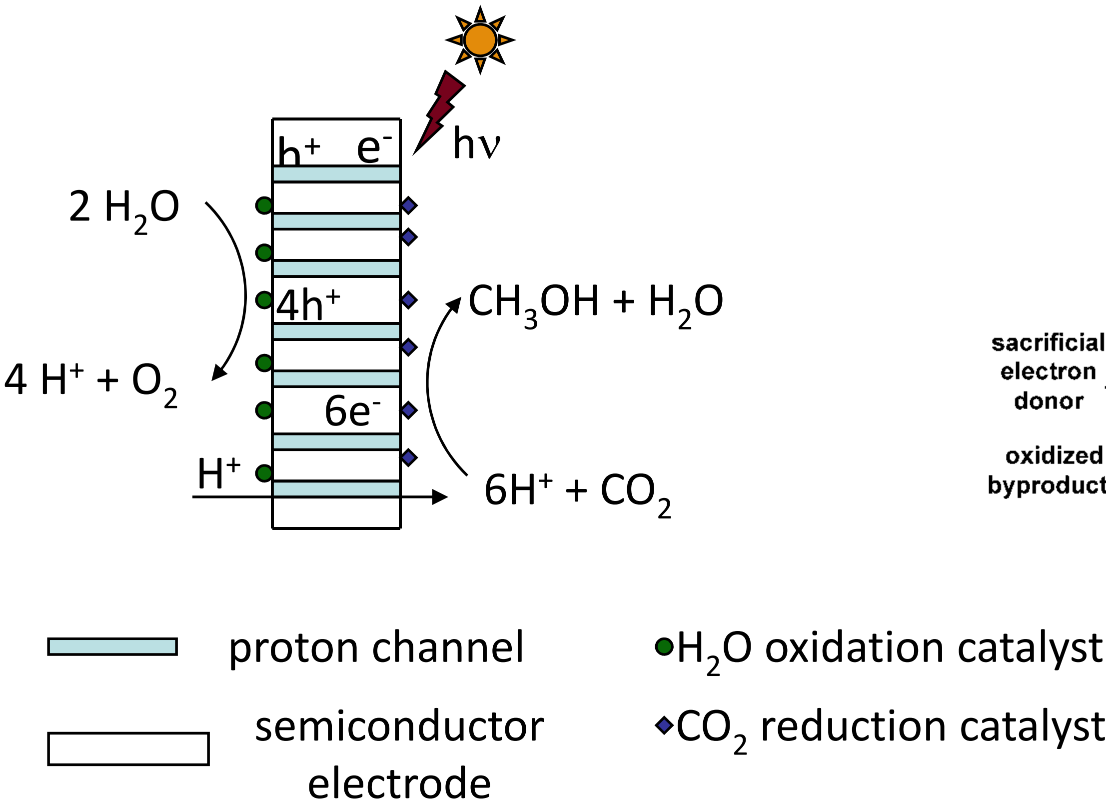


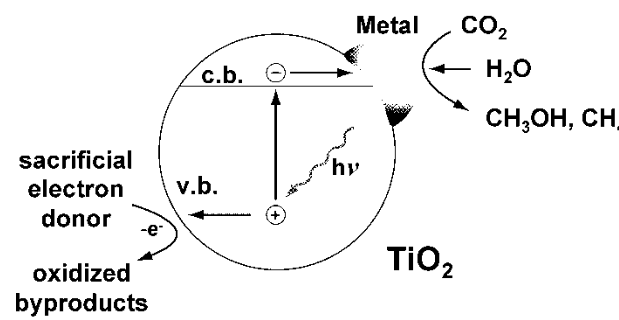


Challenge: To understand the relationships of catalyst composition and structure to the elementary processes leading to the generation of H_2

Challenge: To identify catalysts that enable the efficient utilization of e-/h+ pairs for the splitting of H_2O and the reduction of CO_2

Advanced Catalysts for Photo- and Electro-Driven Conversion of H_2O and CO_2





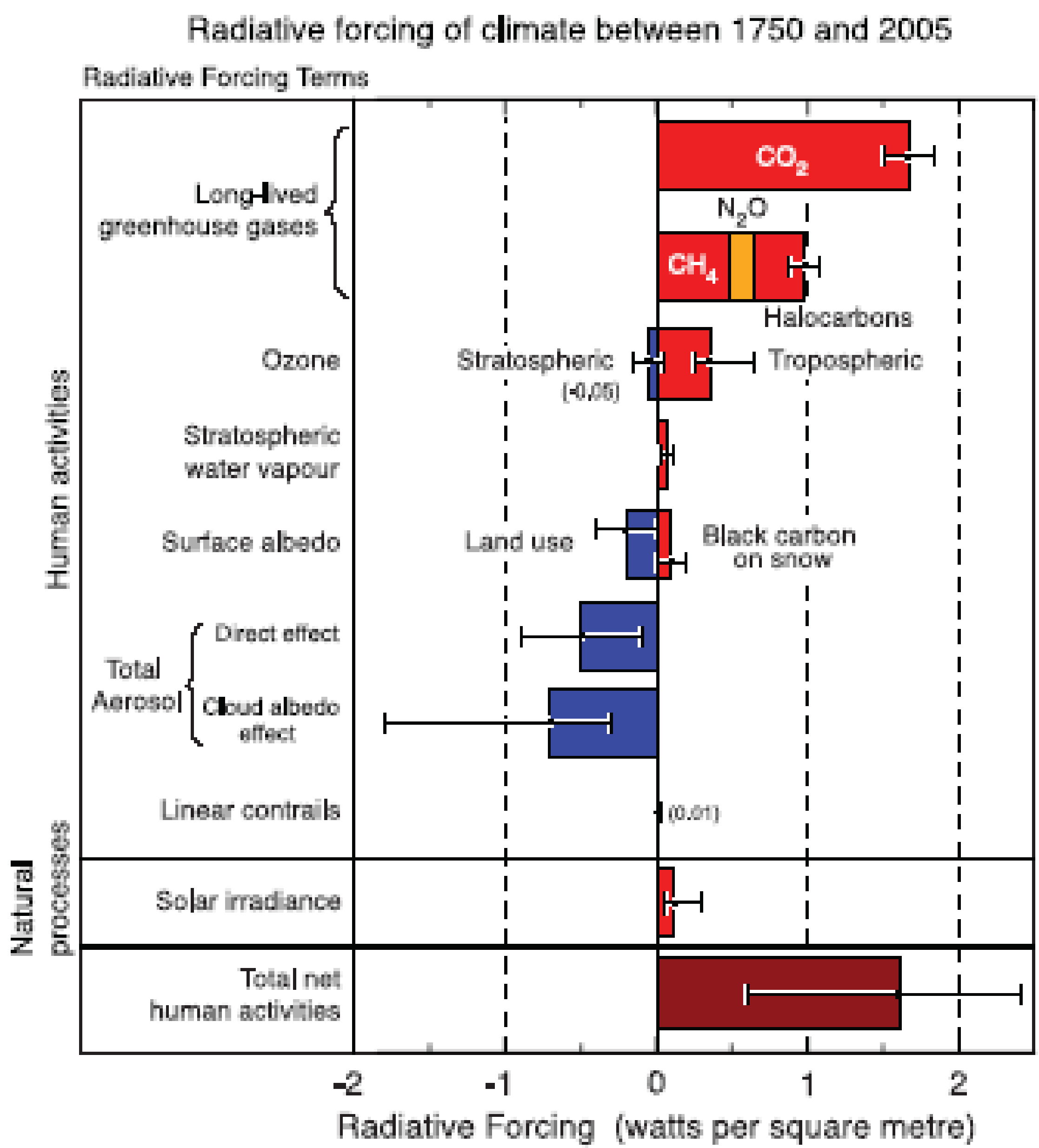
Challenge: To design efficient catalysts for the photo- or electro-reduction of CO_2

Geoengineering for Climate Stabilization

- **The concept of geoengineering – the deliberate modification of global climate through engineering – has received considerable attention because of a recent paper published by Paul Crutzen, a 1995 chemistry Nobel laureate for his work for the hole in ozone layer.**

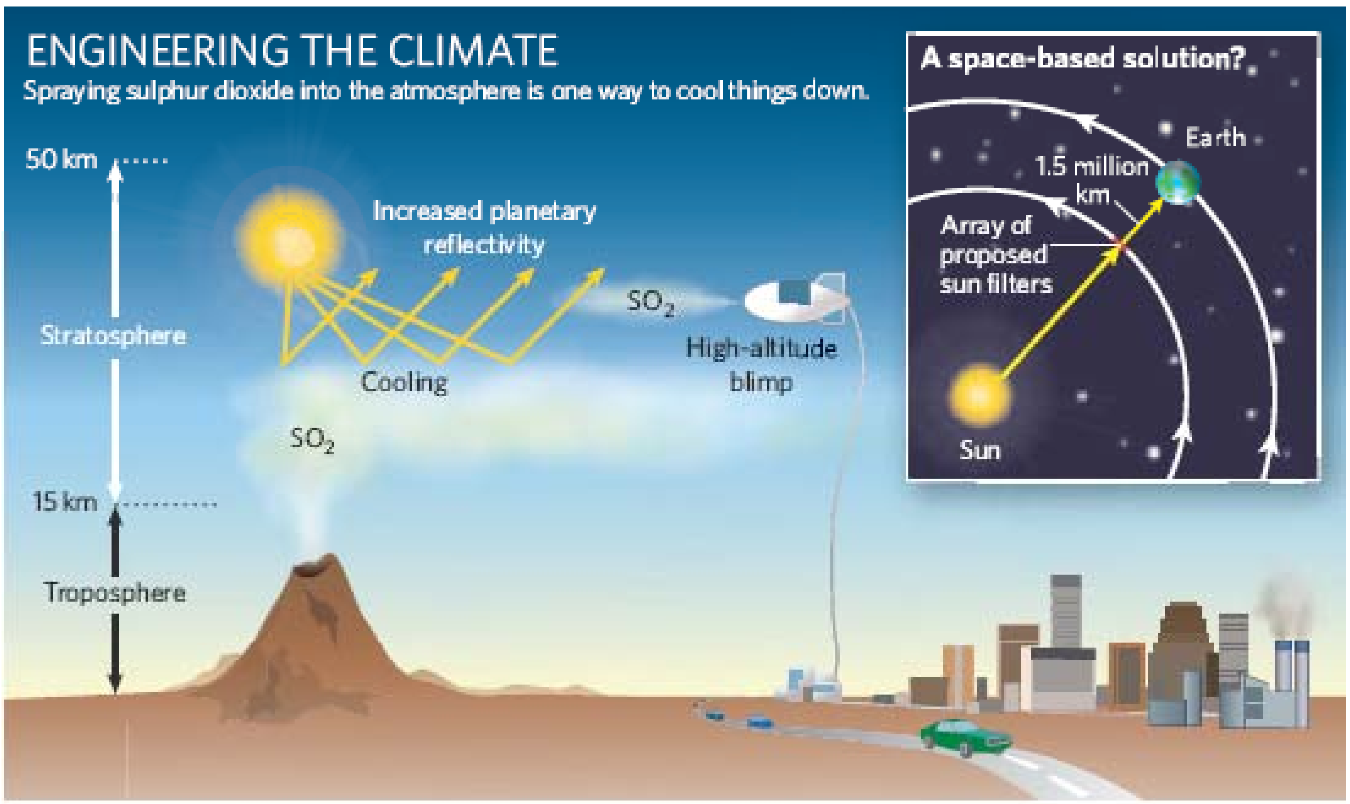
- **He believes that the international political attempts to limit anthropogenic GHG emissions are so limited that a technological contingency plan is needed to avoid large and undesirable climate impacts.**

Greenhouse gasses and their global mean radiative forcings



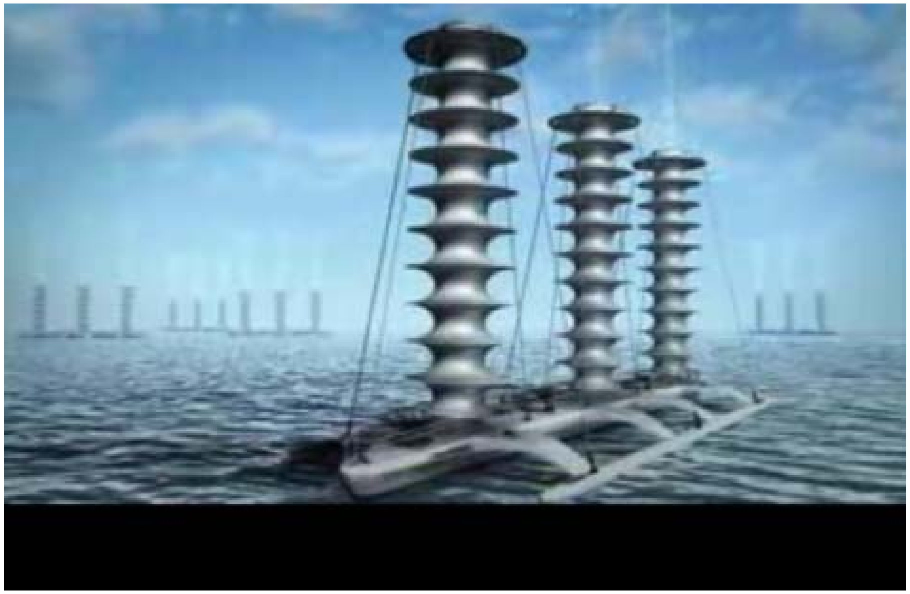
Four Geoengineering Approaches

- Stratospheric aerosols
- Cloud albedo enhancement
- Ocean iron fertilization
- Sunshade geoengineering



Cloud Albedo Enhancement

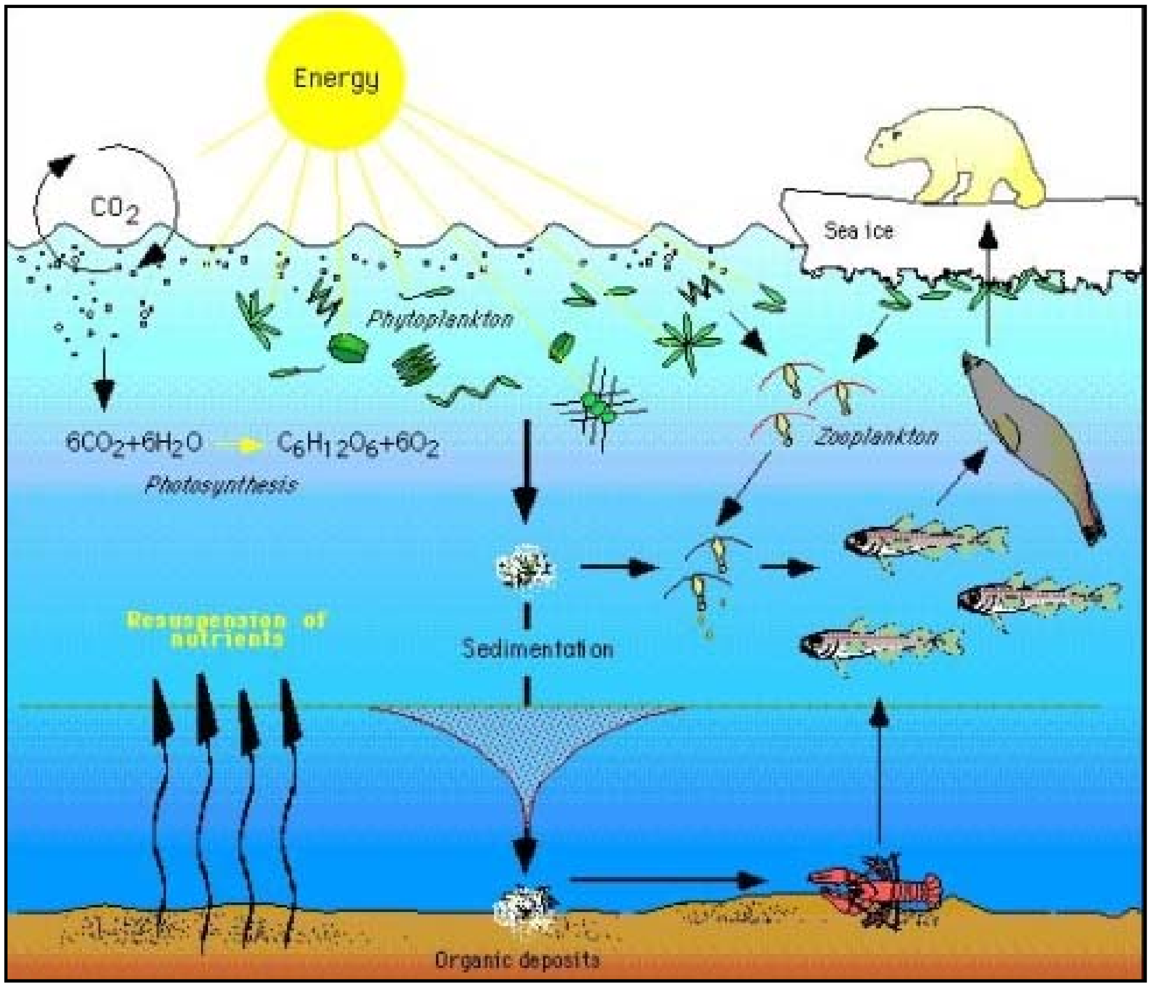
- Generation of fine mist of seawater droplets as nucleation centers for stratocumulus cloud formation.
- Cloud albedo could be controlled from satellites.
- The droplet disseminators and the vessels that carry them would derive their energy from the wind.



J. Latham, Nature 1990

Marine Food Web

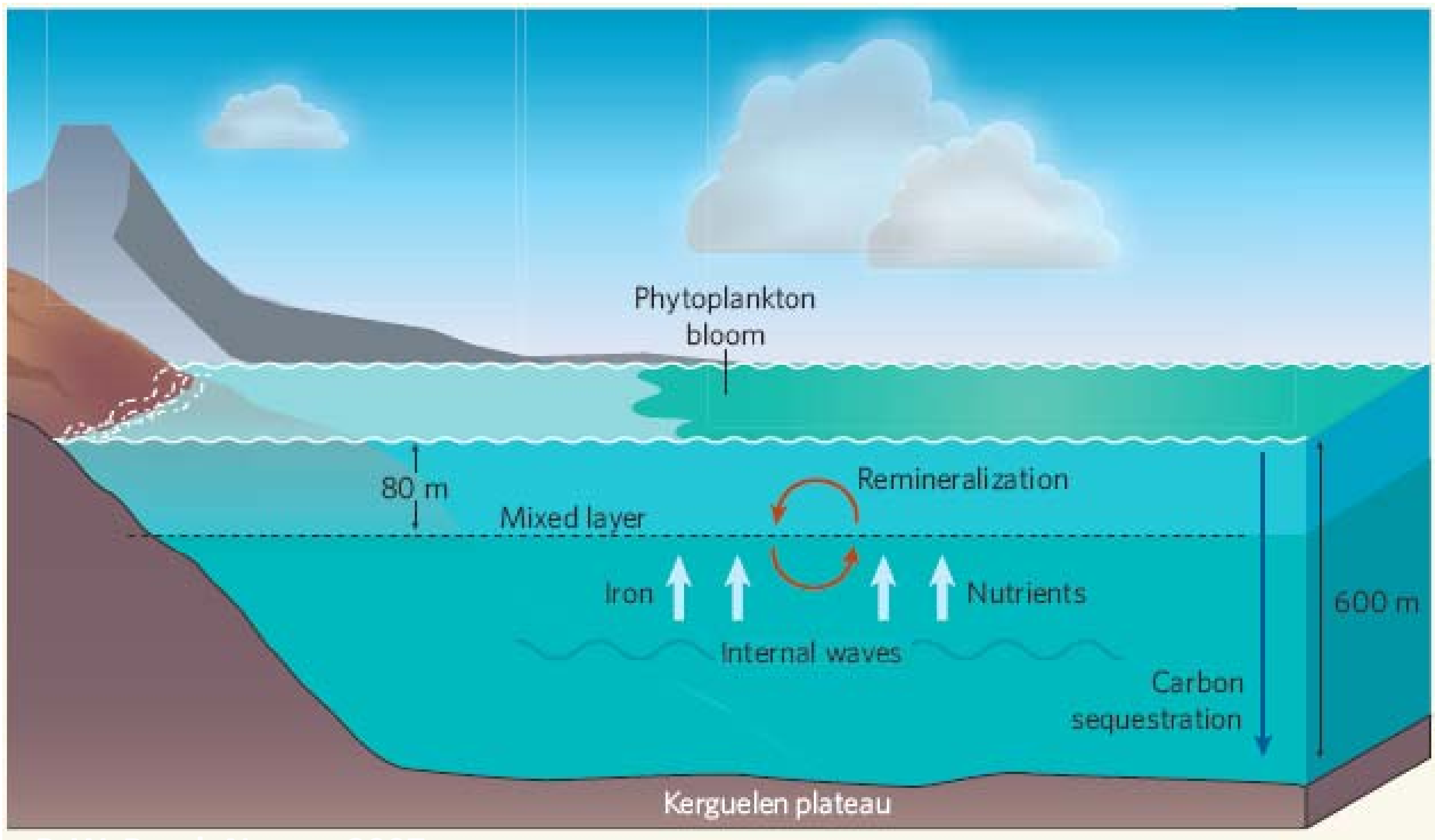
- Phytoplankton are food for the zooplankton, who are eaten by fish and on up to large marine mammals.
- Photosynthesis of phytoplankton absorbs CO_2.



Picture credit:
NOAA, C. Krembs

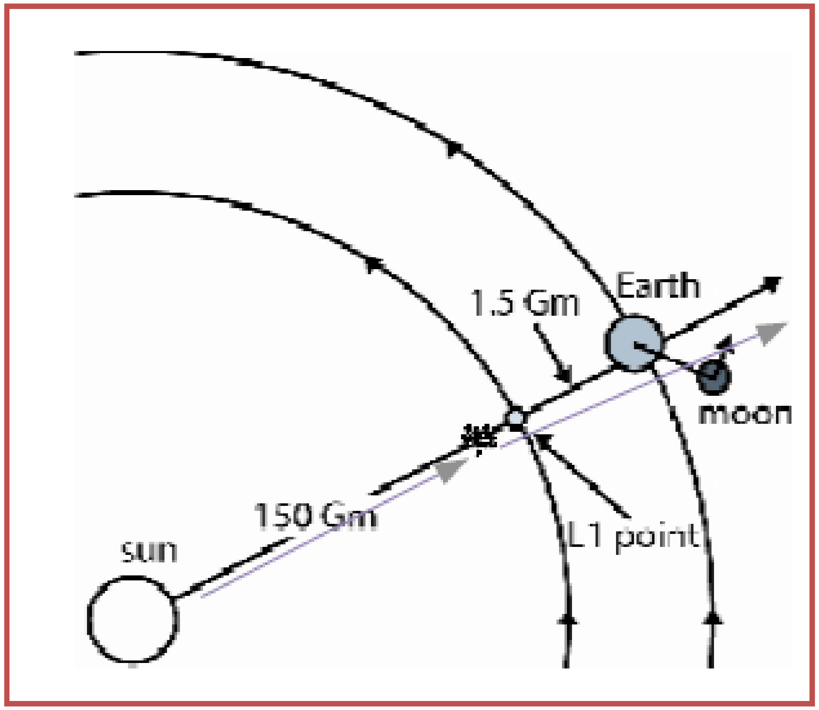
Phytoplankton Bloom In Southern Ocean

Internal ocean waves carry continual iron and nourishment to the phytoplankton which contributes to sequestration of atmospheric CO_2

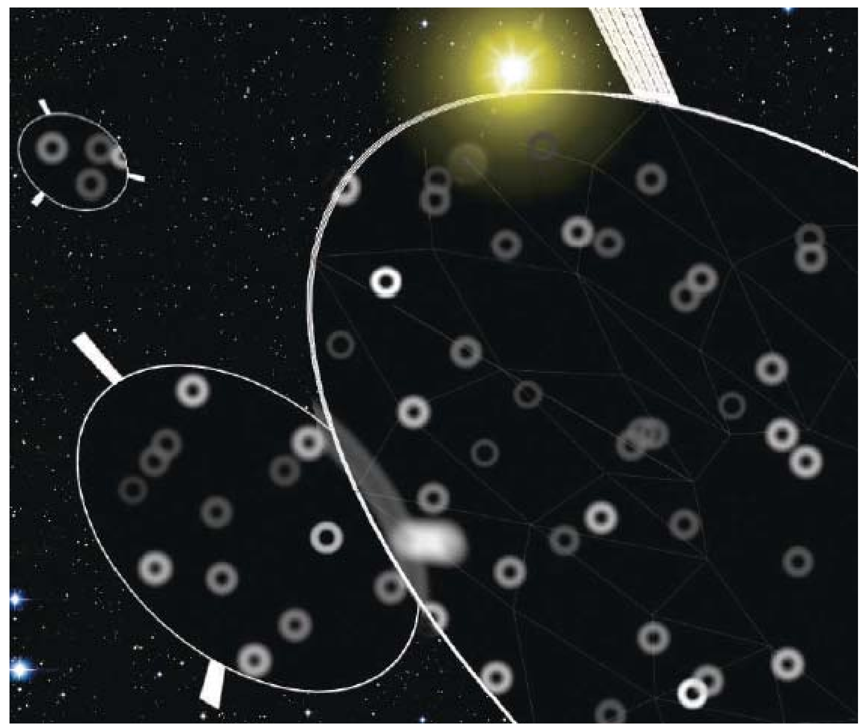


Sunshade Geoengineering

- Use a large number of almost-transparent reflectors (sulfate and other kind of particles) orbited near the inner Lagrange point (L1).
- The L1 point is the preferred location, since it is at a position where objects may track with period of the Earth around the Sun.



NASA workshop report 2006



O. Morton, Nature 2007