Natural Resources Canada   Ressources naturelles Canada

CO_2 Capture and Reuse

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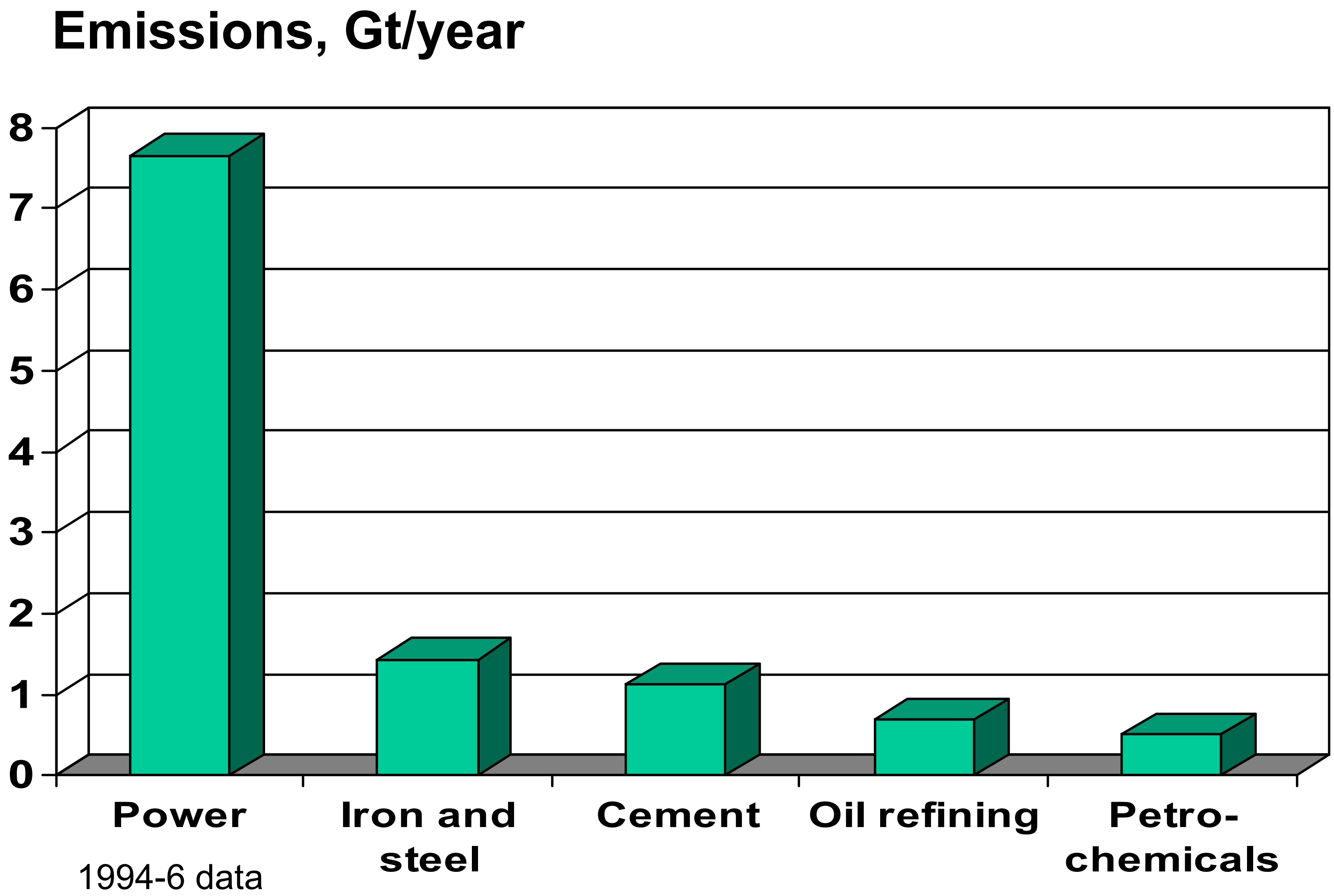
www.ieagreen.org.uk and www.cetc.nrcan.gc.ca

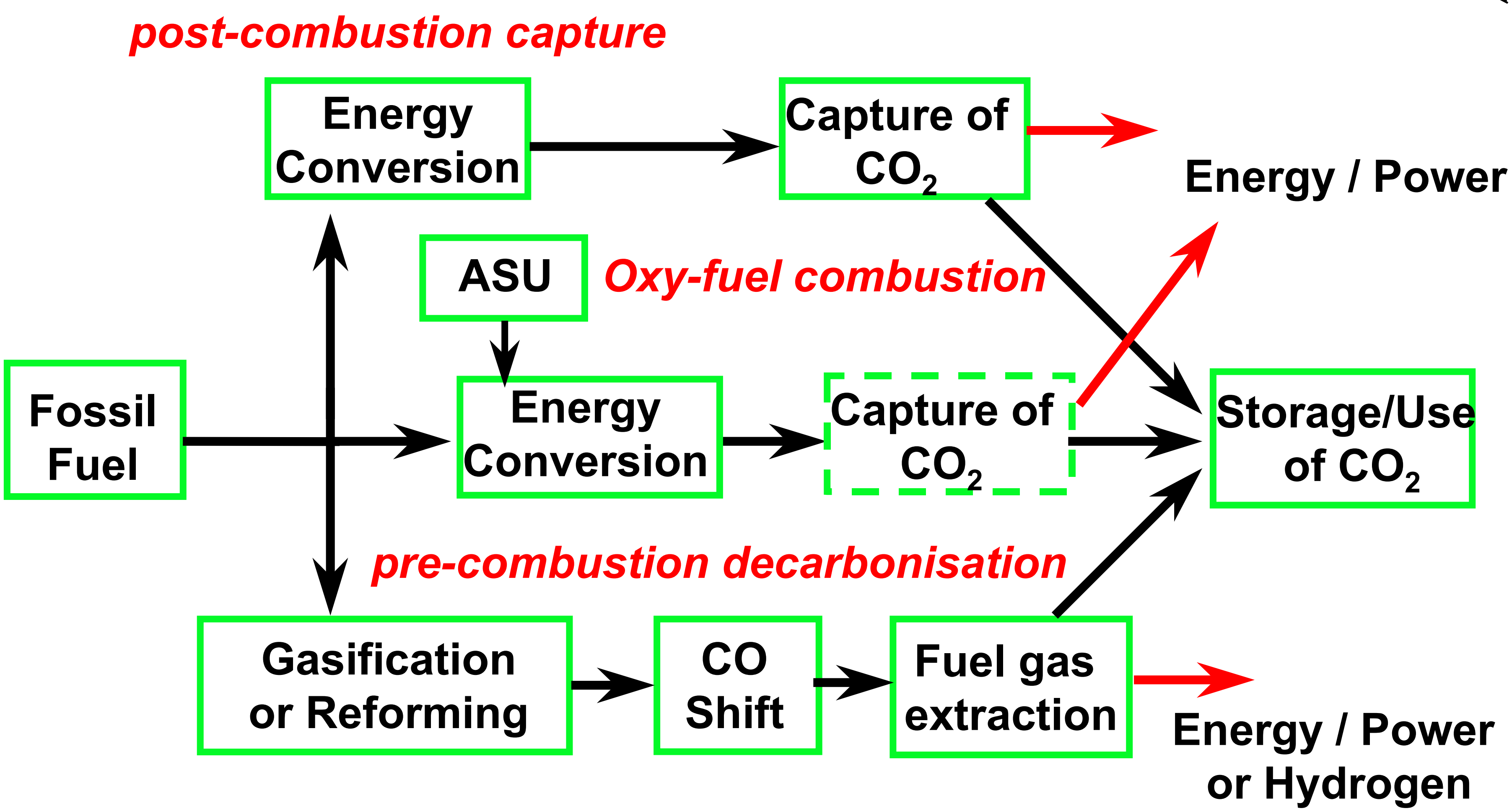
Overview of the Presentation

- Where to capture CO_2
- How to capture CO_2
- Performance and costs of CO_2 capture
- CO_2 utilisation or reuse

CO_2 Emissions

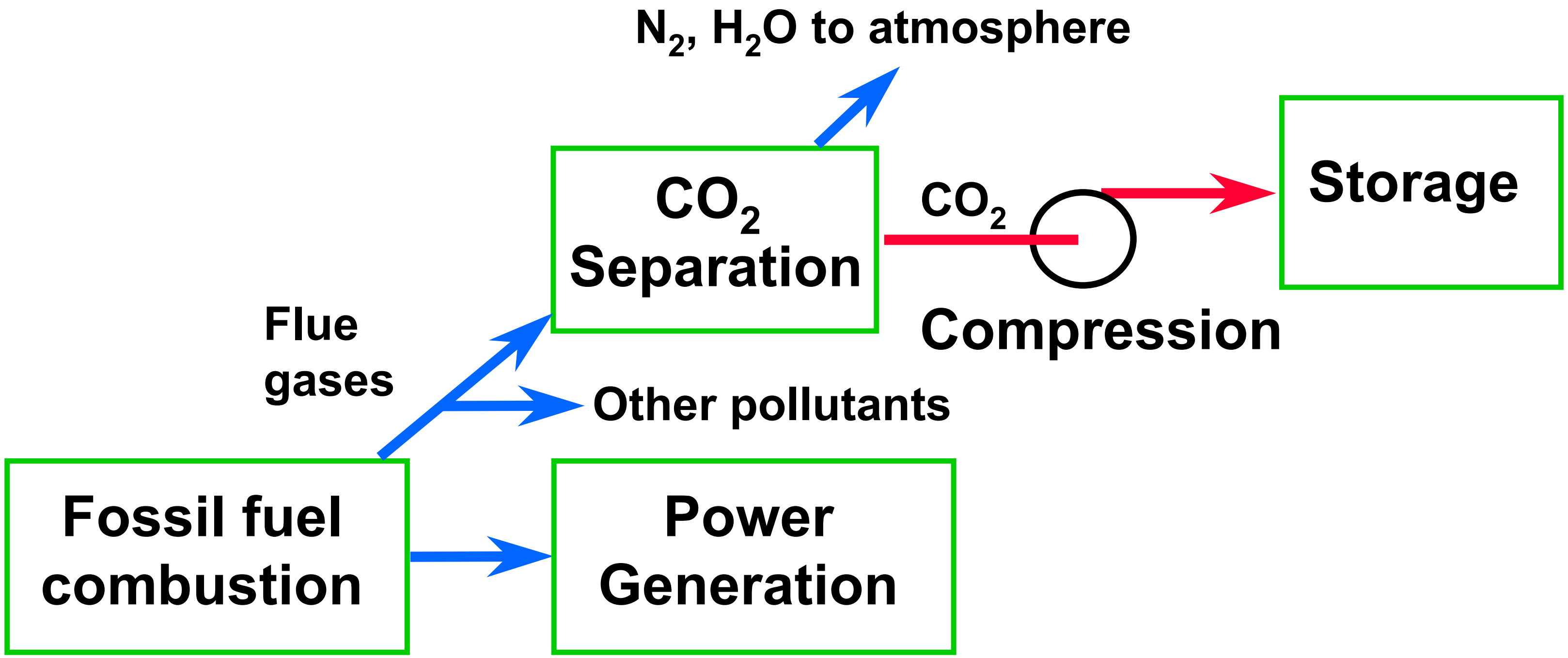


How to Capture CO_2



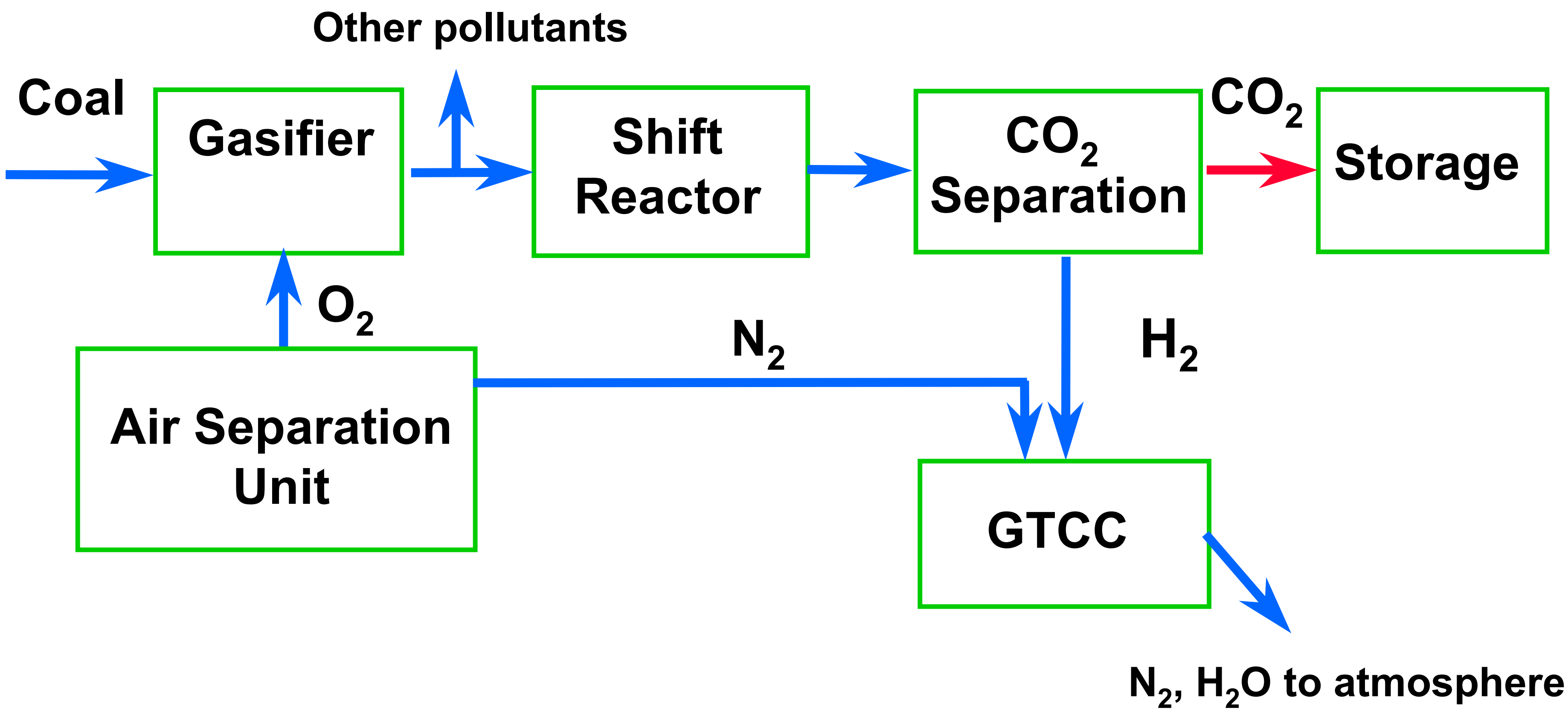
Post combustion capture

Conventional power plant



Capture Before Combustion

Coal-fired power plant (IGCC)



Pre-Combustion Capture

Advantages

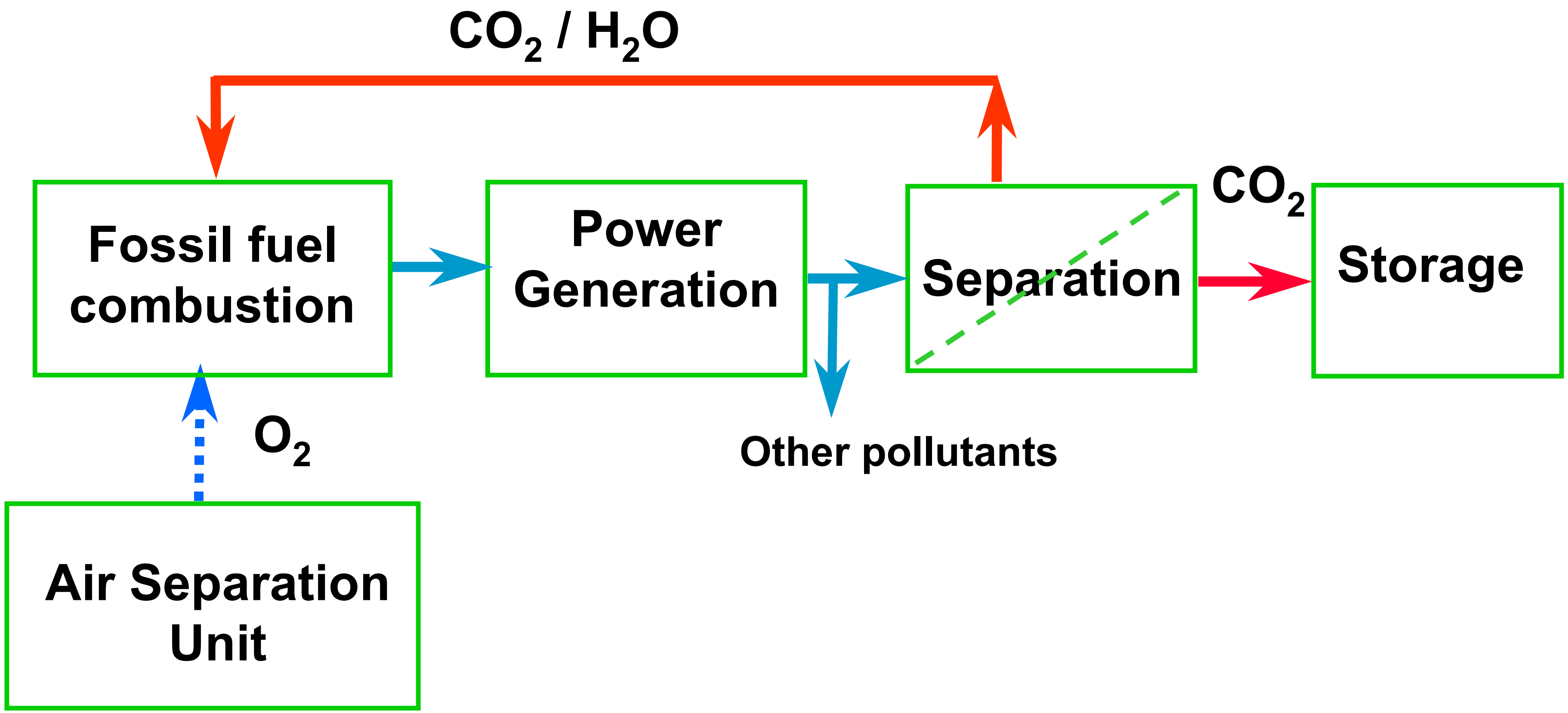
- Generally higher CO_2 concentration than for post-combustion capture
- Higher pressure
  - More compact equipment
  - Higher driving force for CO_2 separation

Disadvantages

- Fuel processing is needed
  - Partially oxidation
    - Needed anyway for coal and oil to remove impurities
  - Shift conversion of fuel gas to H_2 and CO_2

Oxyfuel combustion

Power generation plant



Oxygen Blown Combustion

- Pulverised coal, gas or oil fired boilers/furnaces
  - Flue gas is recycled to avoid excessively high combustion temperatures
- Circulating fluidised bed combustors
  - No flue gas recycle is needed – cooled recycled solids limit the temperature, as in conventional CFBC
- Gas turbines
  - CO_2 is recycled to the compressor to provide the expansion medium, instead of air
  - Novel turbine cycles have been proposed including IGCC (eliminates shift reaction / fuel gas CO_2 separation)
- Fuel Cells
  - Use of oxyfuel after burner

Oxygen Blown Combustion

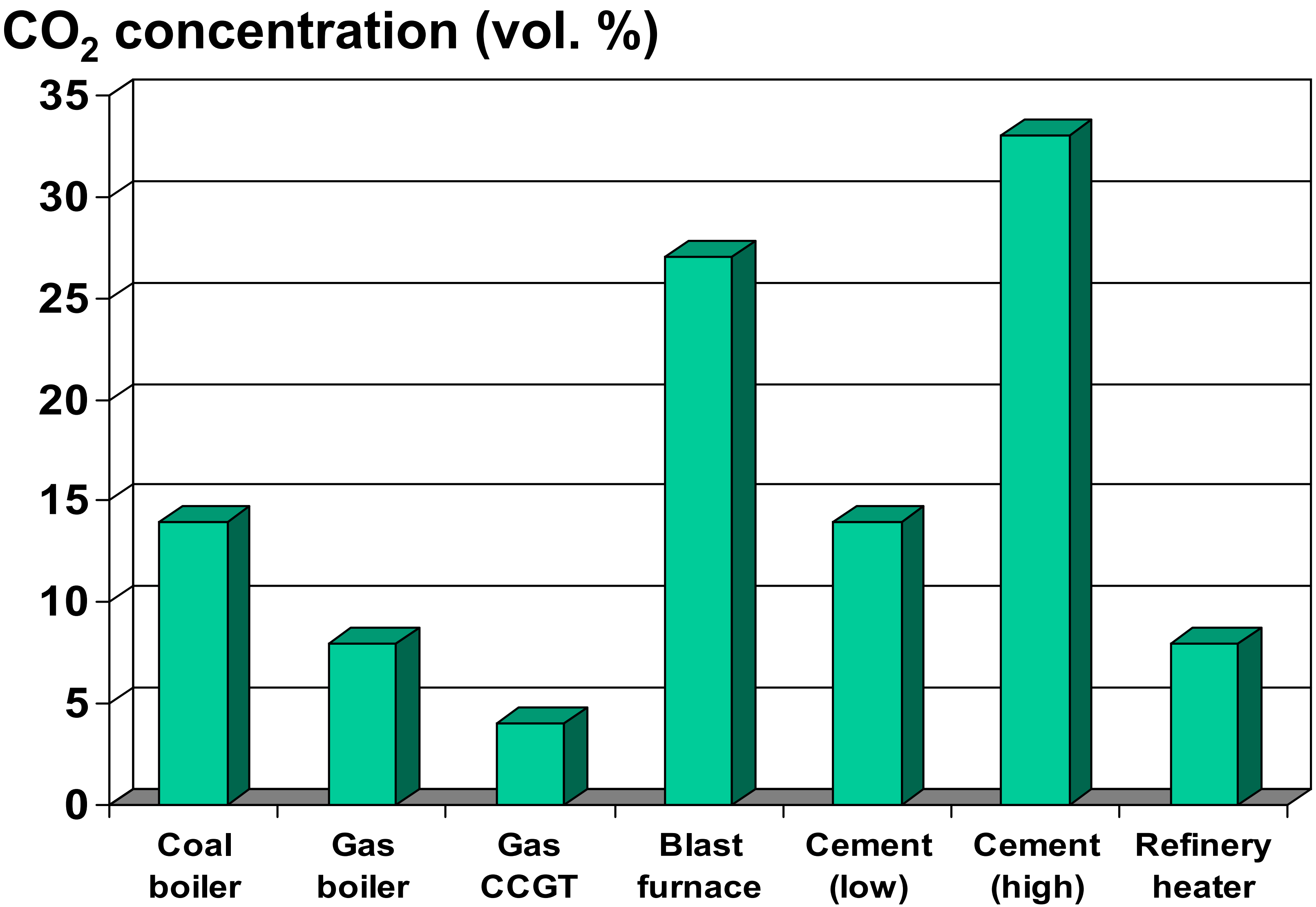
Advantages

- Combustors would be fairly conventional
- May be able to avoid FGD
  - Store the SO_x and NO_2 along with the CO_2

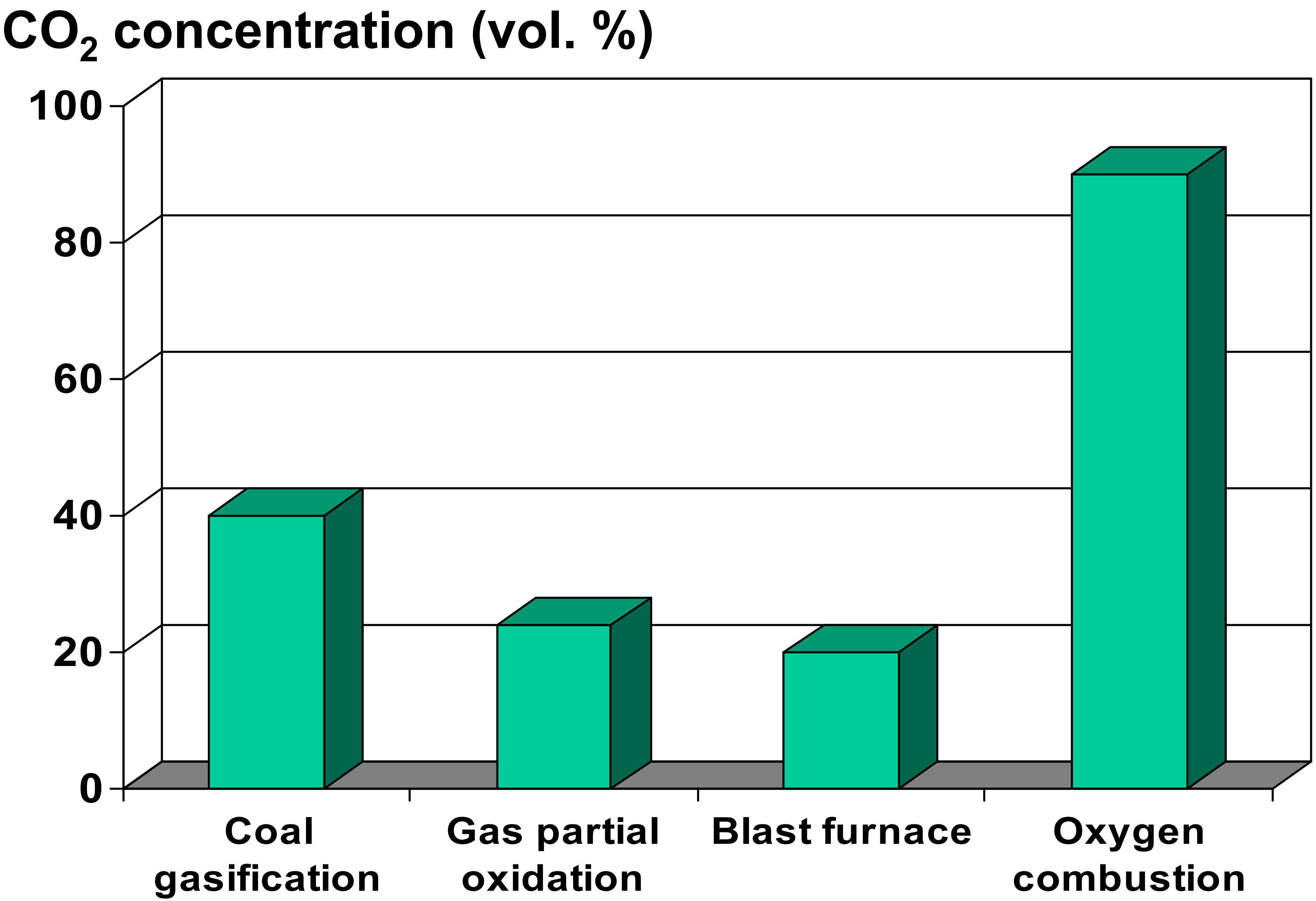
Disadvantages

- High cost of oxygen production
- Need to recycle large quantities of flue gas
  - Not needed for circulating fluidised bed combustors
- Potential for advanced oxygen separation membranes with lower energy consumption

CO_2 Capture After Combustion



Capture Before/During Combustion



Current Status of Technologies

- Post-combustion capture (amine scrubbing)
  - Amine scrubbing well established for natural gas etc.
  - Some small power plants operating
  - Solvent degradation is a problem
- Pre-combustion capture
  - IGCC and ammonia production are established
  - Physical solvent separation well established
  - Gas turbines must be capable of using H_2-rich fuel
- Oxygen-blown combustion
  - Oxygen production is well established
  - Small scale combustor test rigs operating

CO_2 Separation Techniques

- Solvent Absorption
  - Chemical solvent
  - Physical solvent
- Adsorption on a solid
  - Pressure Swing Adsorption (PSA)
  - Temperature Swing Adsorption (TSA)
  - Electric Swing Adsorption (ESA)
- Membranes
  - Gas separation membranes
  - Gas absorption membranes
- Cryogenics

Novel Capture Techniques

Chemical looping combustion

- A fuel is contacted with a metal oxide, which releases oxygen for combustion
- The oxide is regenerated by reaction with air in a separate vessel
- Degradation of the oxide material is a concern

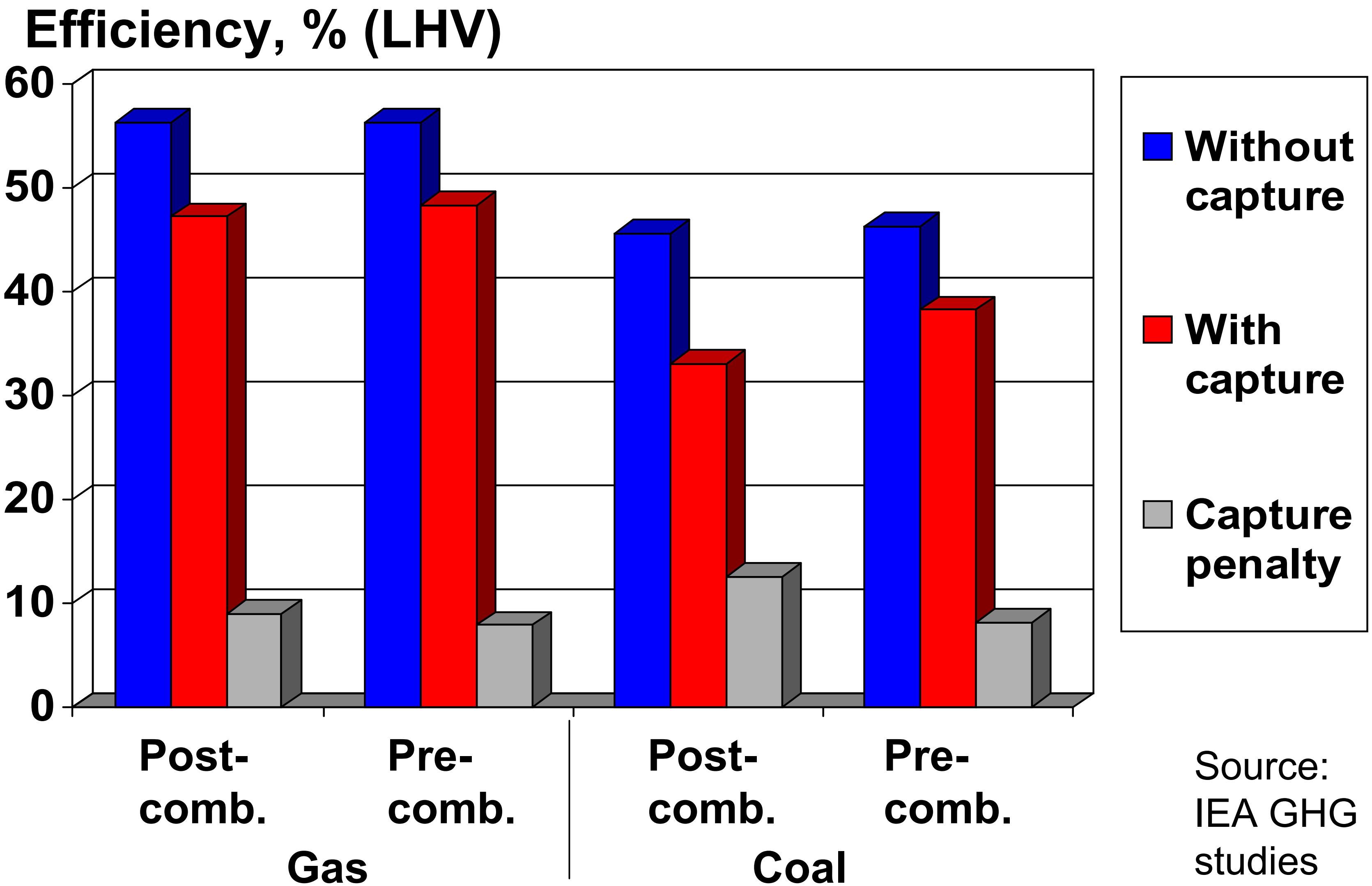
CO_2 capture in fuel cells

- Modifications for CO_2 capture in fuel cells could be relatively small

Performance and Costs

- Results are presented from a variety of recent studies
- Results of studies vary due to many factors, e.g.
  - Fuel analyses
  - Ambient conditions
  - Types of gas turbine
  - Steam conditions
  - Percentage CO_2 capture
  - CO_2 compression pressure (or no compression)
  - Plant location

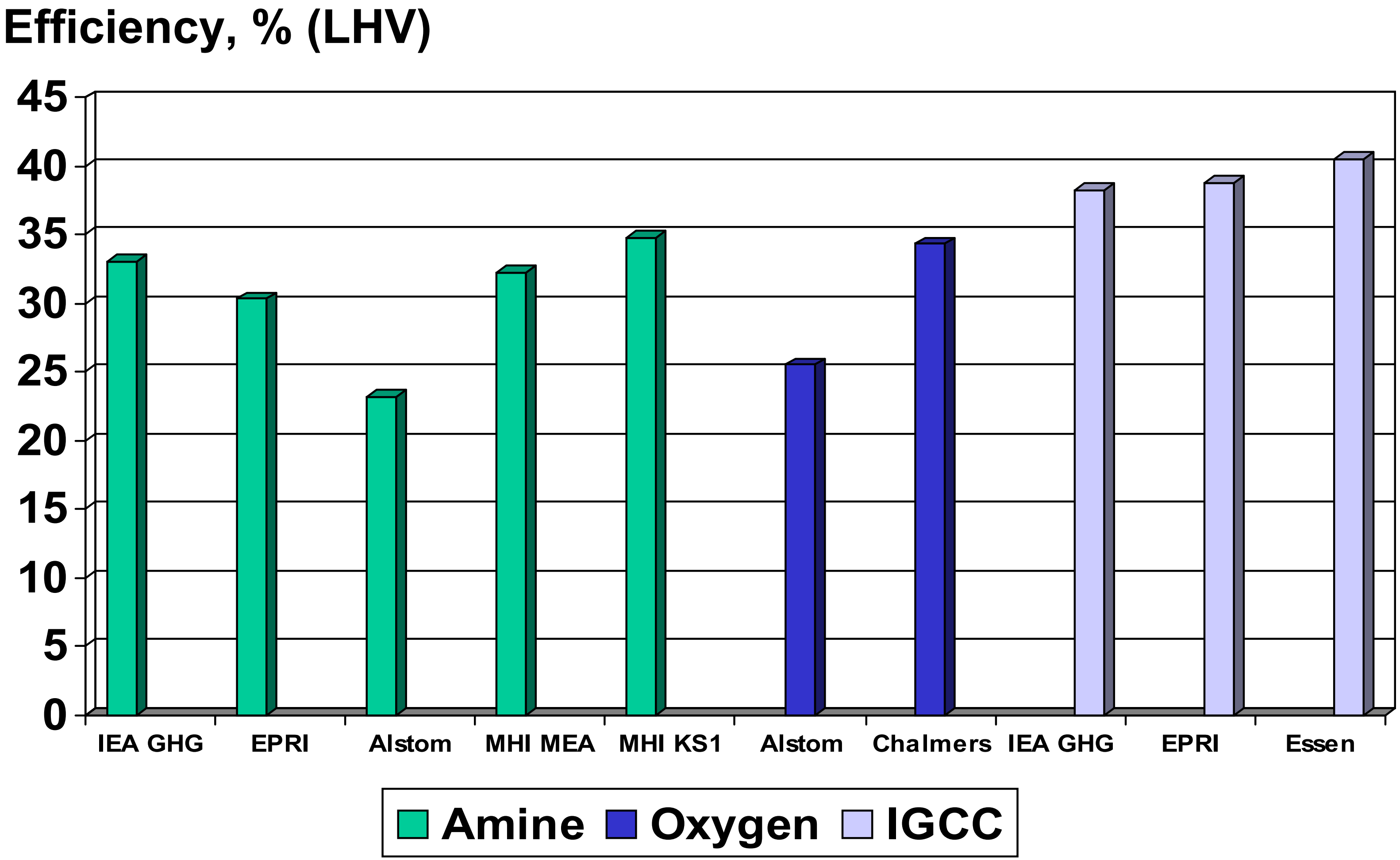
Power Generation Efficiency



Source: IEA GHG studies

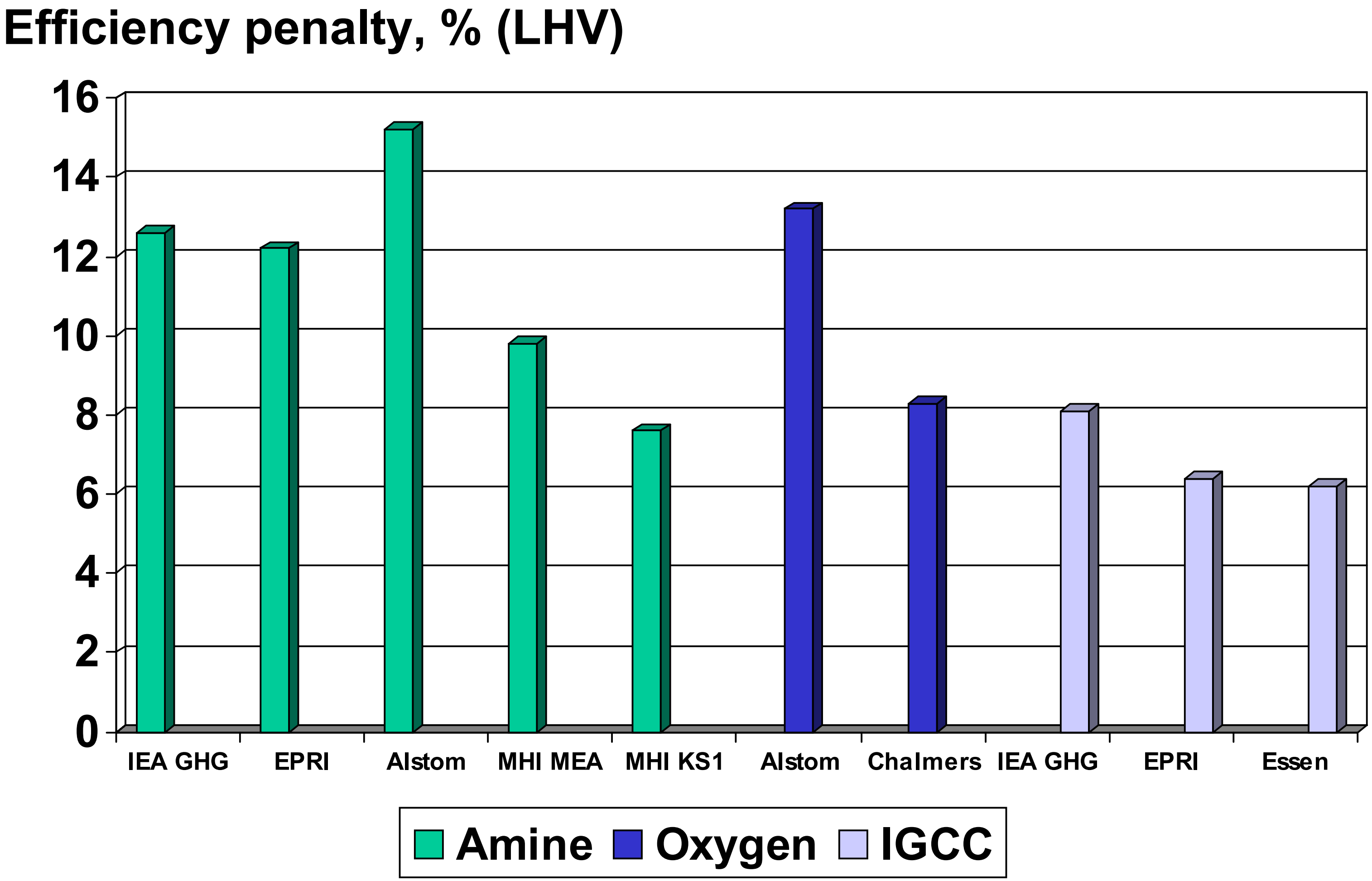
Efficiencies of Plants with Capture

Coal fired power plants



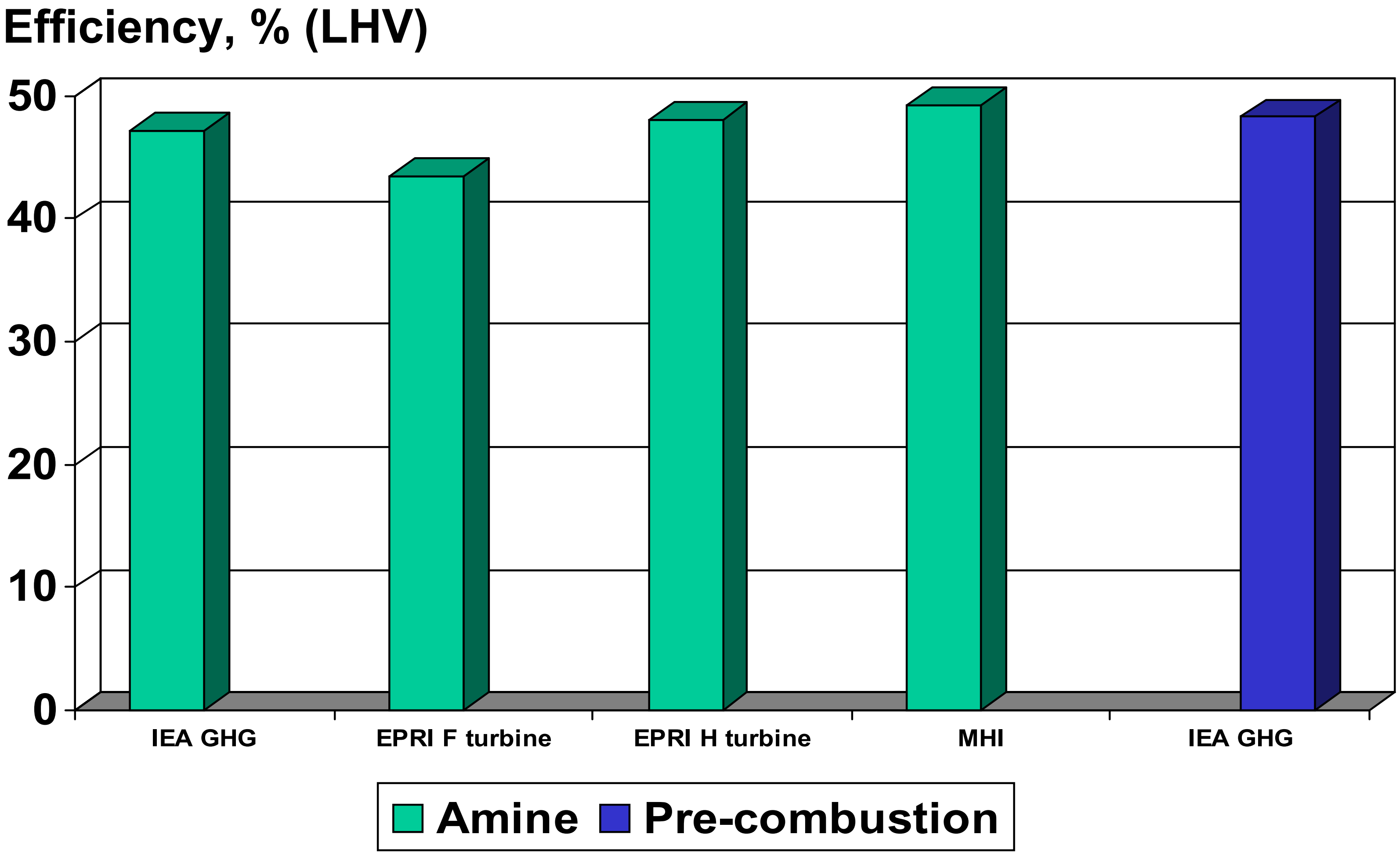
Efficiency Penalty for Capture

Coal fired power plants



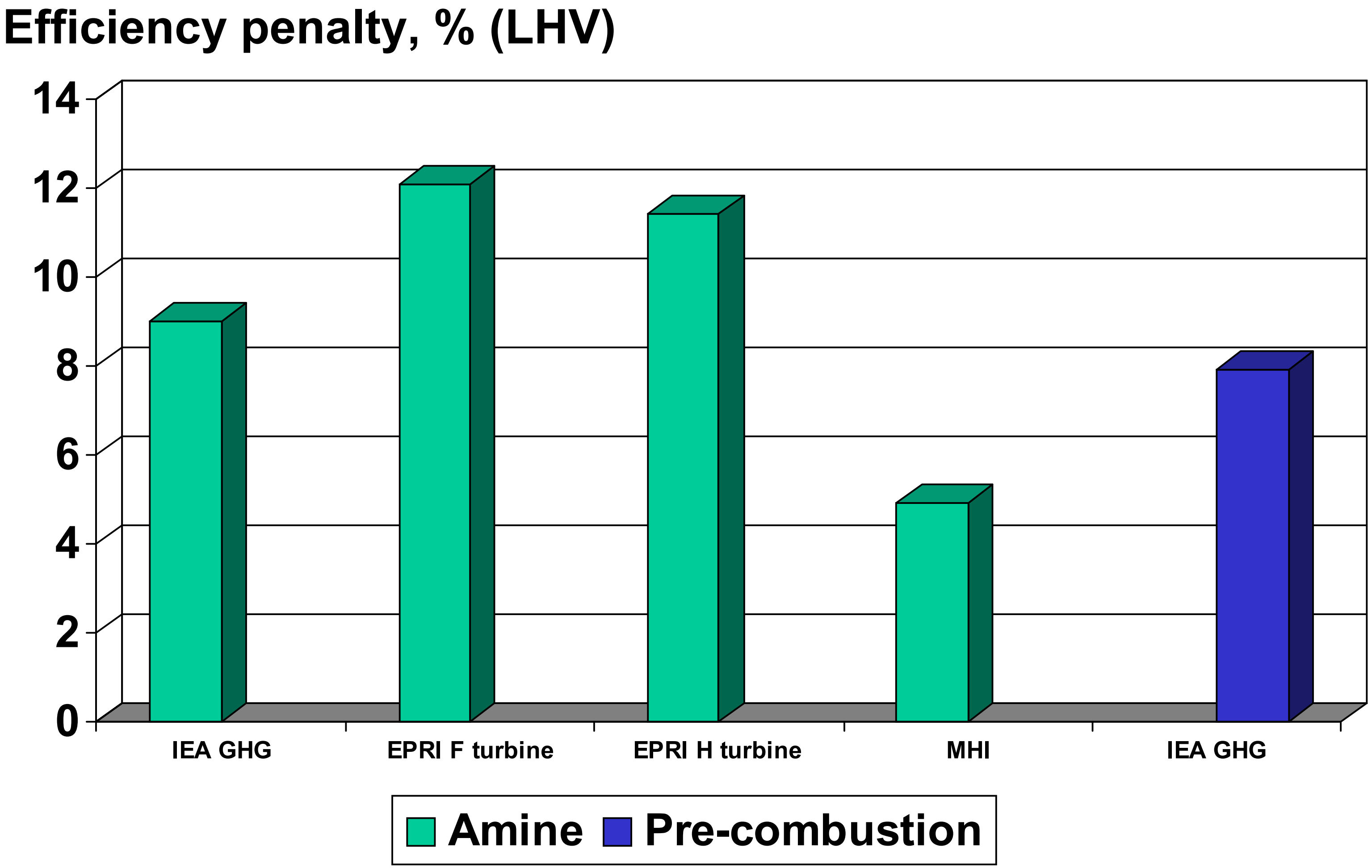
Efficiencies of Plants with Capture

Gas fired combined cycle plants



Efficiency Penalty for Capture

Gas fired combined cycle plants



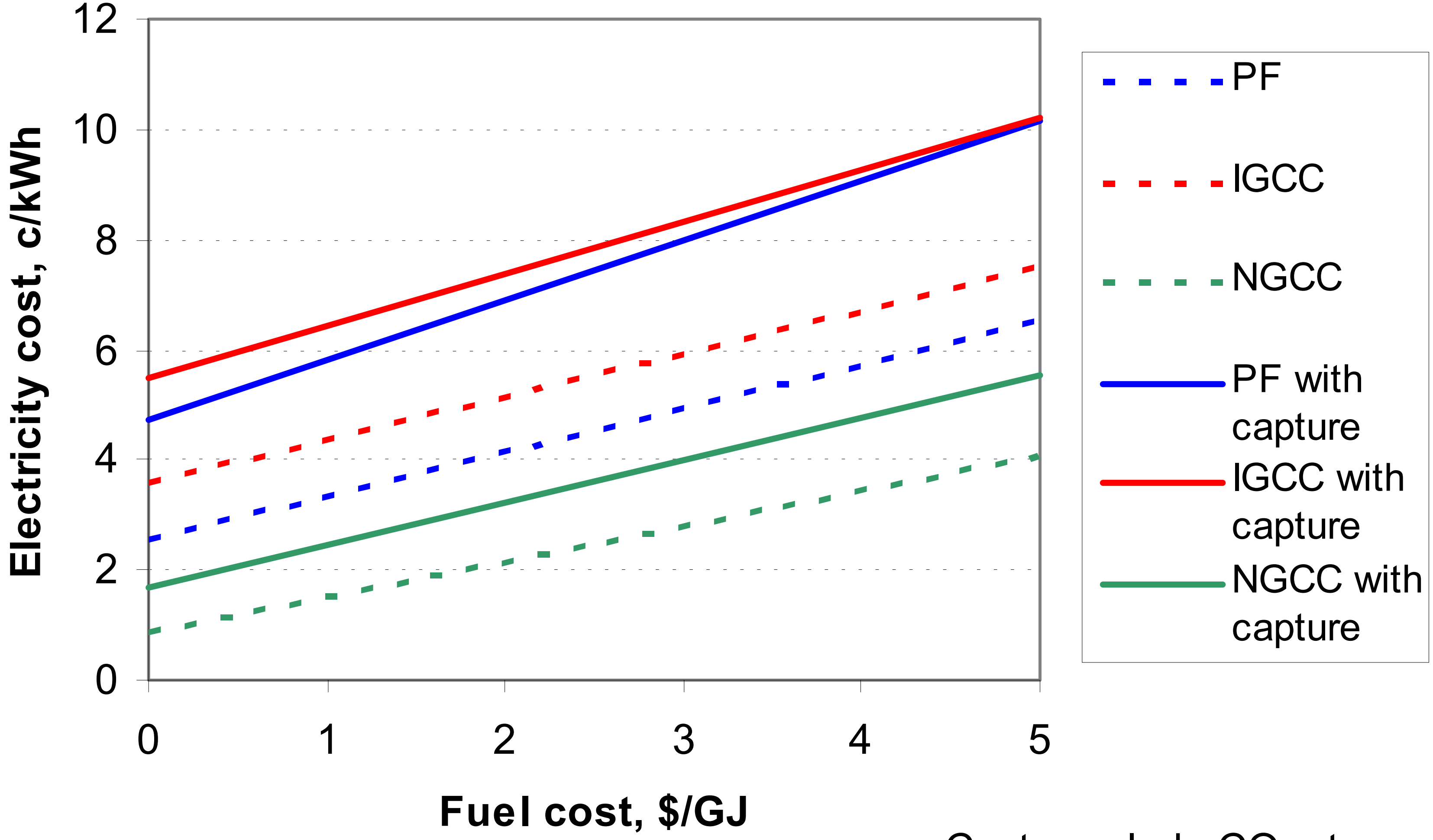
Post-Combustion Capture

- Efficiency and cost penalties for coal fired power plants with conventional MEA scrubbing are reasonably well known
- More uncertainty about natural gas CCGTs
- Improved solvents etc. may reduce energy losses by 40%
- Significant cost savings are possible

Pre-Combustion Capture

- For coal plants, efficiency and cost penalties are generally lower than for post-combustion capture
- For gas CCGTs, efficiency and cost penalties are about the same as for post-combustion capture
- Efficiency and cost penalties depend on the type of coal gasifier
  - Gasifiers with coal slurry feeding and water quench of the product gas tend to have lower capture penalties but lower overall efficiencies
- Coal fired IGCCs without capture tend to have high overall costs

Cost of CO_2 Capture



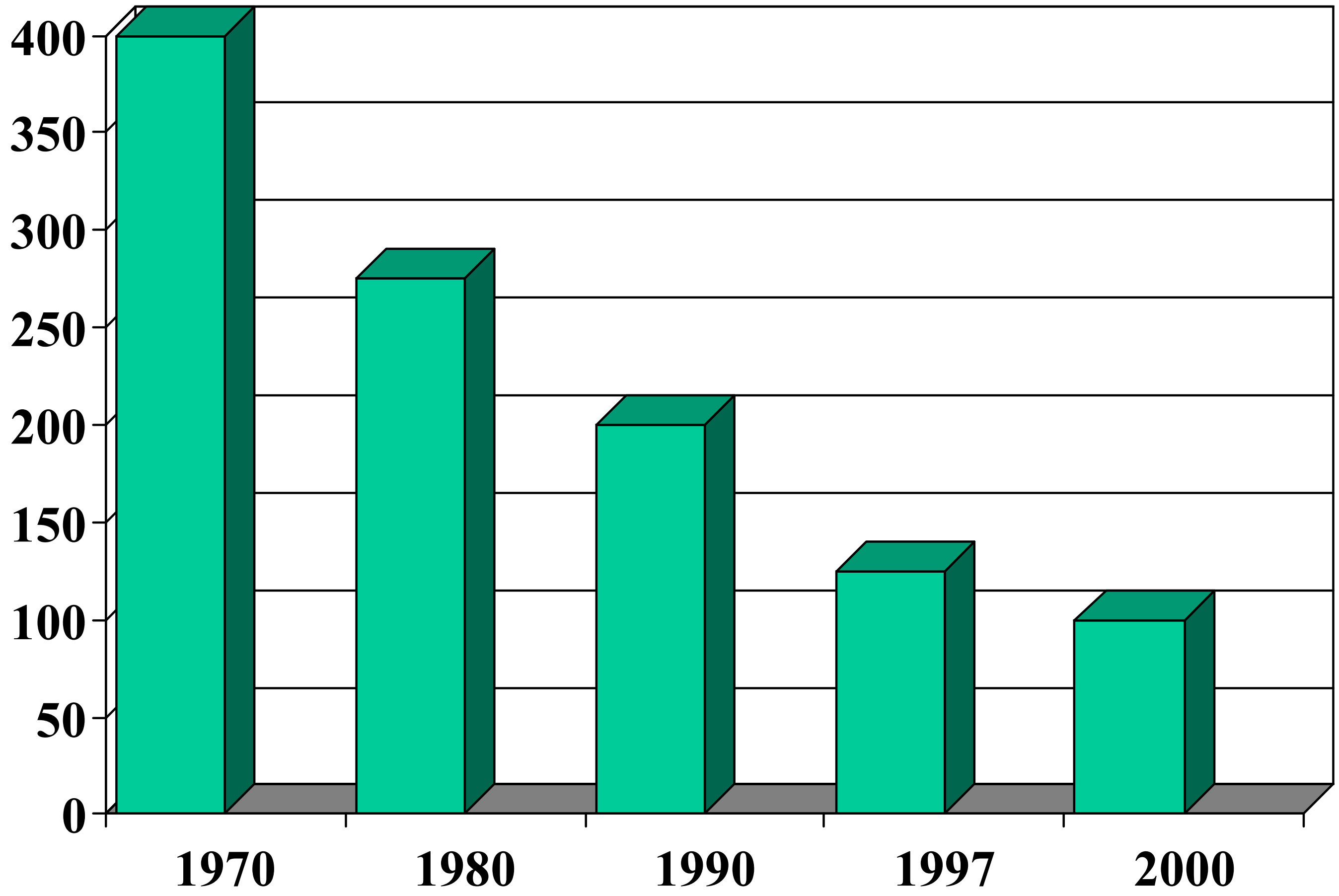
Costs exclude CO_2 storage

Potential for Cost Reductions

- Stretch improvements will be made to existing technologies
- Costs of other emission control technologies have reduced substantially
- Continuing R&D and development of a market for products is needed to stimulate cost reductions
- Technological breakthroughs may produce large cost reductions

Progress in FGD Costs

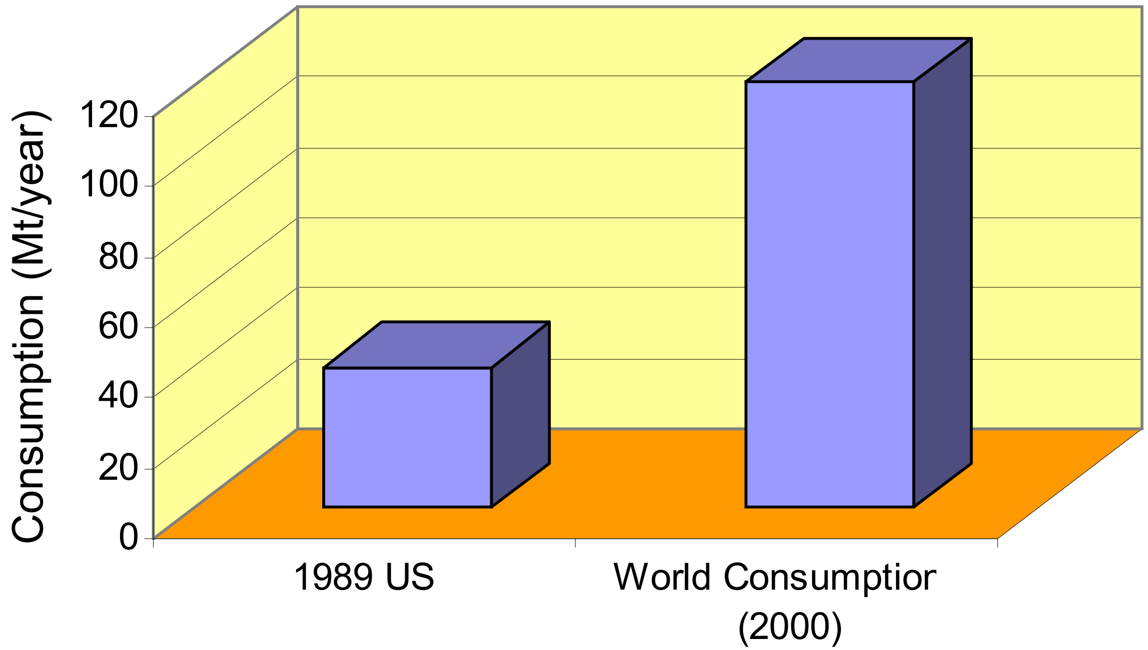
Capital cost, $\$/kW_e$



IEA Clean Coal Centre data

CO_2 Reuse

- Industrial Uses of CO_2



- In 2000, 117 Mt/y of CO_2 consumed in chemical synthesis (75%) and in CO_2-EOR (25 %)
- In 2000, ~24 Gt/y of anthropogenic CO_2 emissions

CO_2 Reuse by Conversion

- Relative Thermodynamic Stability of CO_2

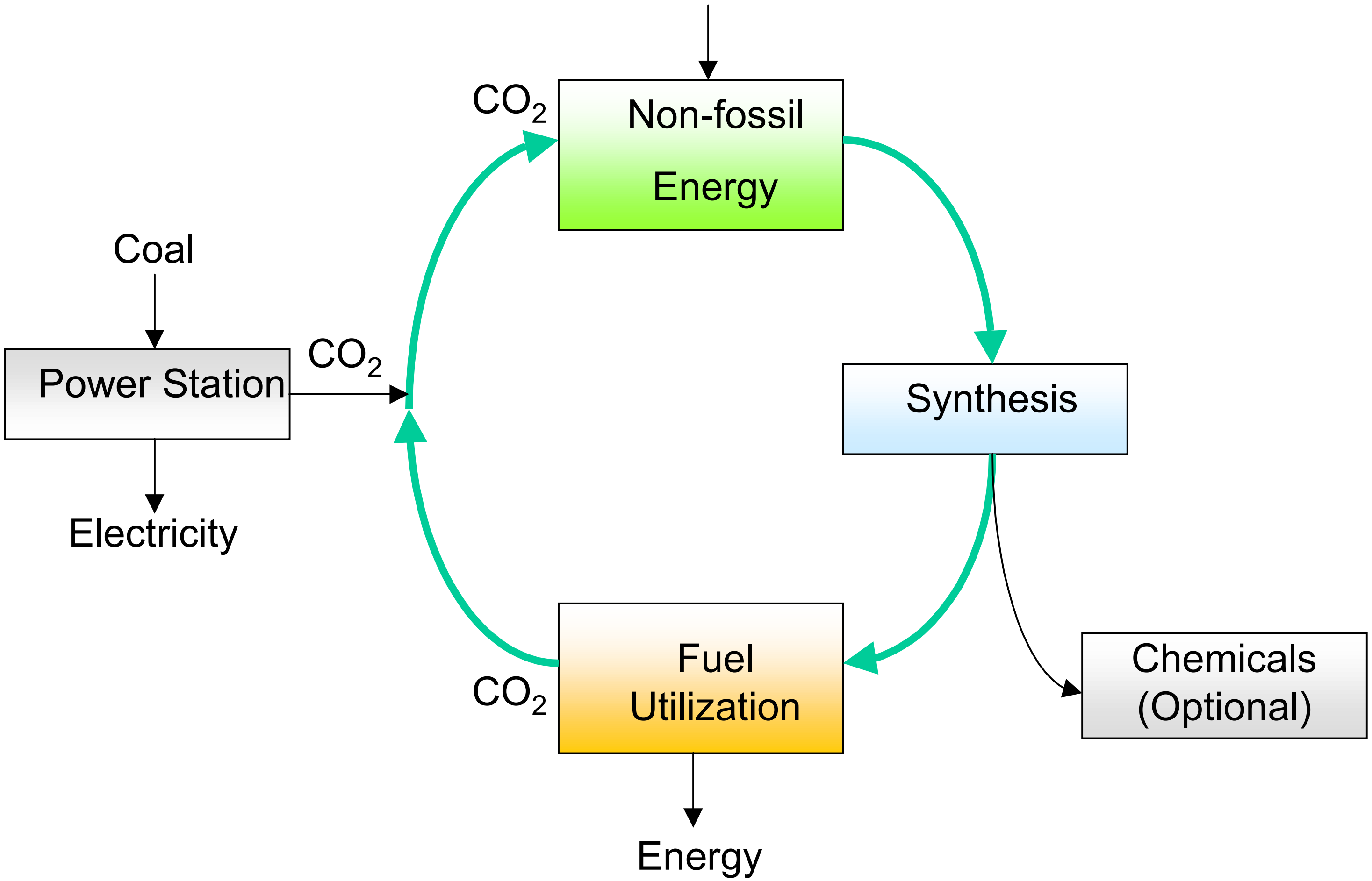
Chemicals	***Free energy of formation, ΔG^o_{298} (kJ/mole)***
Benzene	+130
Ethylene	+68
Methane	-51
Urea	-197
H_2O (l)	-237
Carbon Dioxide (CO_2)	***-394***
Dimethyl Carbonate	-492
Magnesium Carbonate	-1012
Calcium Carbonate	-1129

Thermodynamic stability

Endothermic conversion

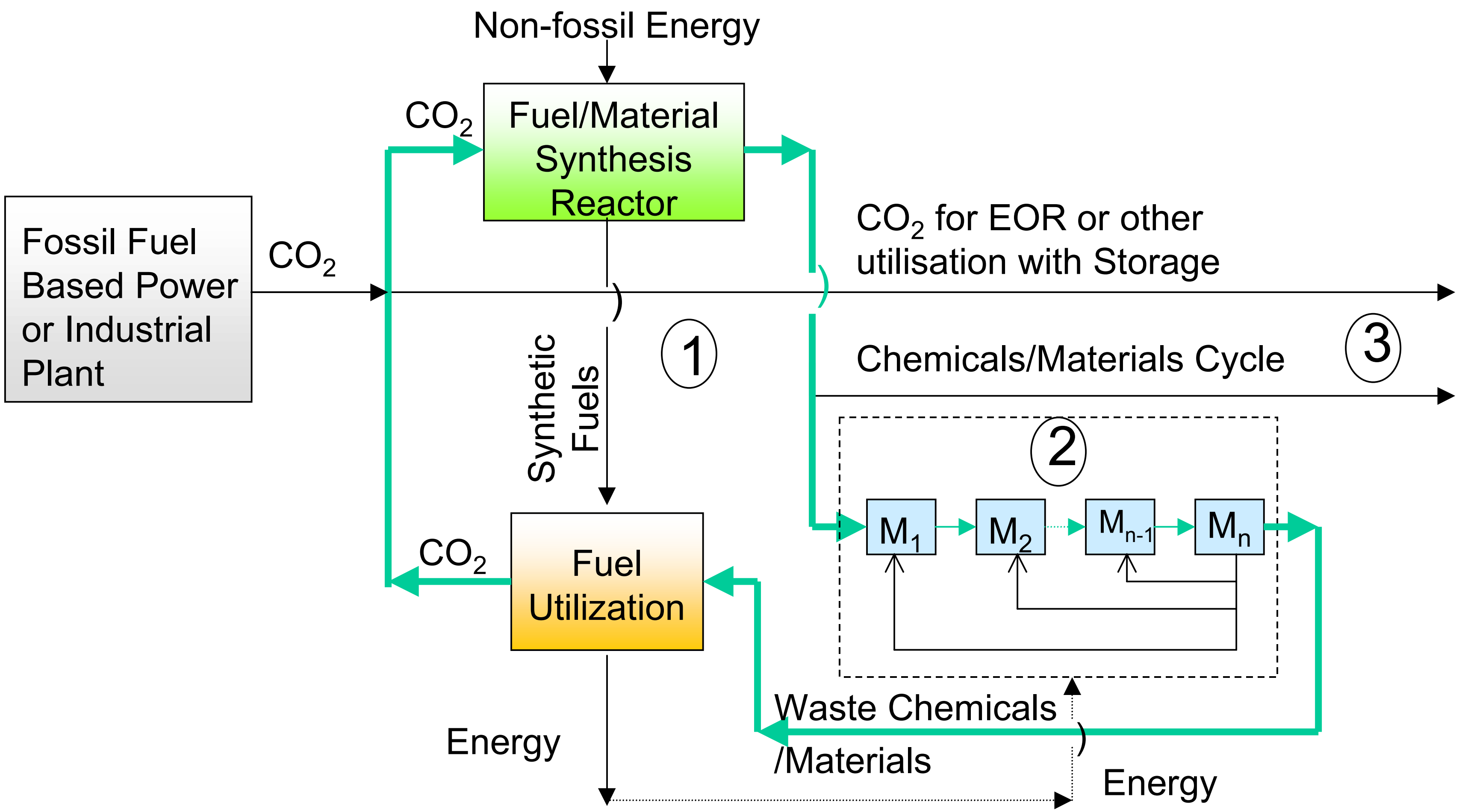
CO_2 conversion, recycling, storage

- CO_2 Based Secondary Energy/Chemical Cycle



CO_2 conversion, recycling, storage

- A Comprehensive CO_2 Based Secondary Energy & Material Utilization Cycle



CO_2 Reuse as Fuels

- Fuels synthesis

Methane synthesis:

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ $\quad \Delta G^o_{298} = 113.6$ kJ/mol

Methyl alcohol:

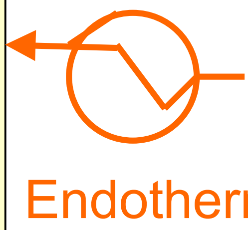
$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$ $\quad \Delta G^o_{298} = 3.9$ kJ/mol

Ethylene synthesis:

$2CO_2 + 2CH_4 \rightarrow 2CO + C_2H_4 + 2H_2O$ $\quad \Delta G^o_{1073\,K} = 35$ kJ/mol

Carbohydrates (photosynthesis):

$nCO_2 + nH_2O \rightarrow C_nH_{2n}O_n + nO_2$ $\quad \Delta G^o_{298} = (+)$ve

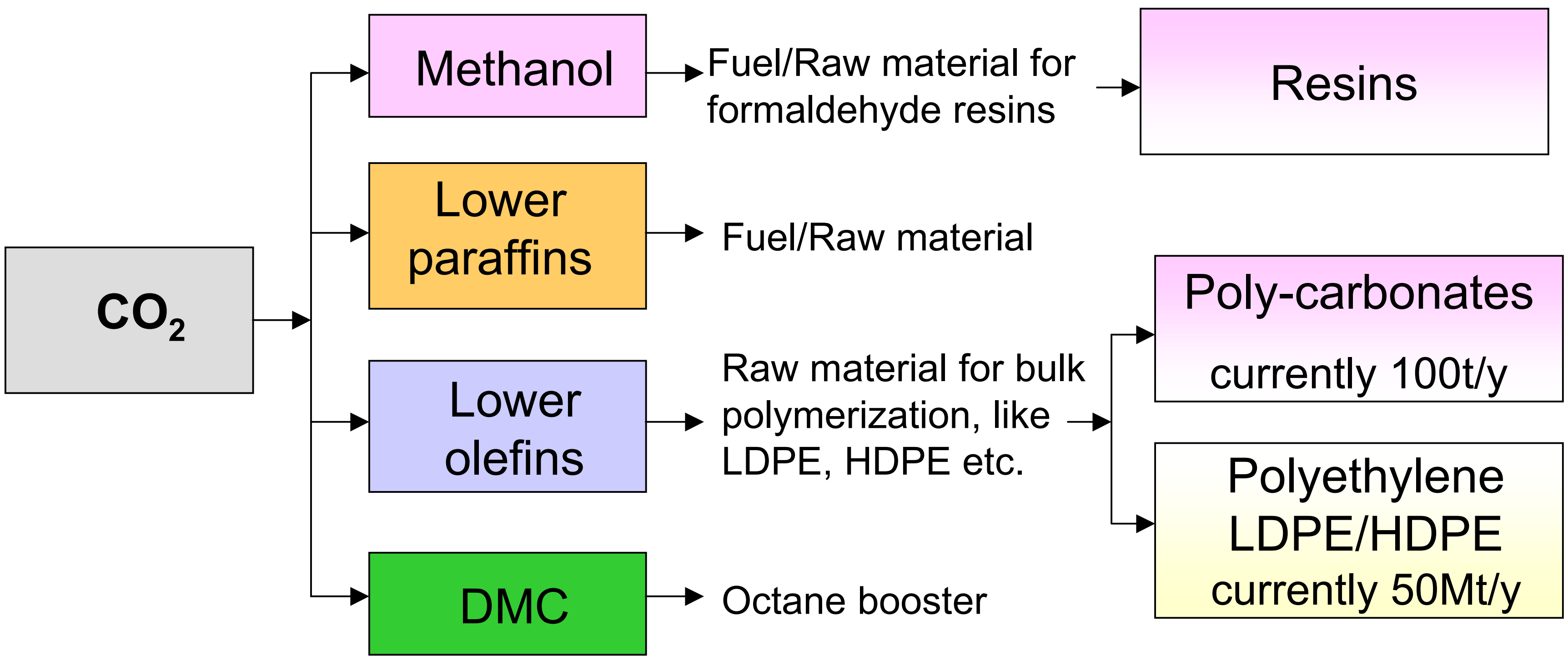


Many fuel synthesis reactions are endothermic and require a source of H_2

Development of reaction pathways and catalysts are also necessary

CO_2 Reuse as Materials

- Intermediate Chemicals & Commodity Materials



Several synthesis reactions are endothermic and/or require a source of H_2; some materials can be recycled or stored indefinitely

CO_2 Reuse with storage

- CO_2-Enhanced Oil Recovery

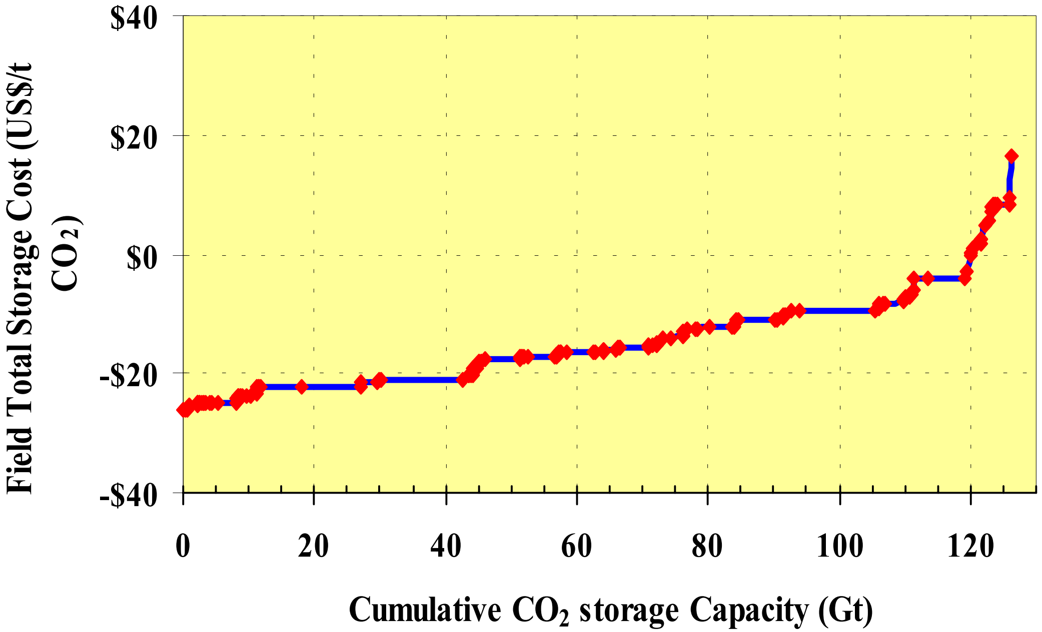
-can enhance the oil recovery by 10-15 %

-can sequester 120 Gt of CO_2

-current consumption is 30 Mt/year (supplied mainly from natural sinks)

Higher the oil prices, lower the cost of CO_2-EOR storage

Estimated at an oil price of $ 15/bbl.



CO_2 Reuse

Conclusion

- The conversion of CO_2 into fuels and chemicals have been assessed in terms of its chemical stability.
- Since CO_2 is a thermodynamically a very stable molecule in a high oxidation state its reuse often requires the input of energy and/or the use of hydrogen for chemical conversion
- The supply of energy and hydrogen for CO_2 ‘fixation’, recycling and storage must be derived from a carbon free energy source for the effective mitigation of anthropogenic emissions – approaches require rigorous life cycle assessments of energy use and emissions
- Current industrial use of CO_2 is 2-3 orders of magnitude lower than the net anthropogenic CO_2 emissions