Greenhouse Effect
and
Electricity Production

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A few figures

- 60 % of the greenhouse effect results from CO_2 emissions.
- CO_2 emissions represented 22500 Million tonnes in 1997.
- CO_2 emissions from electricity generation represented 7650 Million tonnes in 1997 i.e 34% of total emissions.

- Power sector CO_2 emissions are particularly important because :
  - electricity generation is expected to grow steadily in the coming decades (≅ 3% per year on overage - ≅ 5% in developing countries).
  - the power sector will probably become more dependent on fossil fuels.

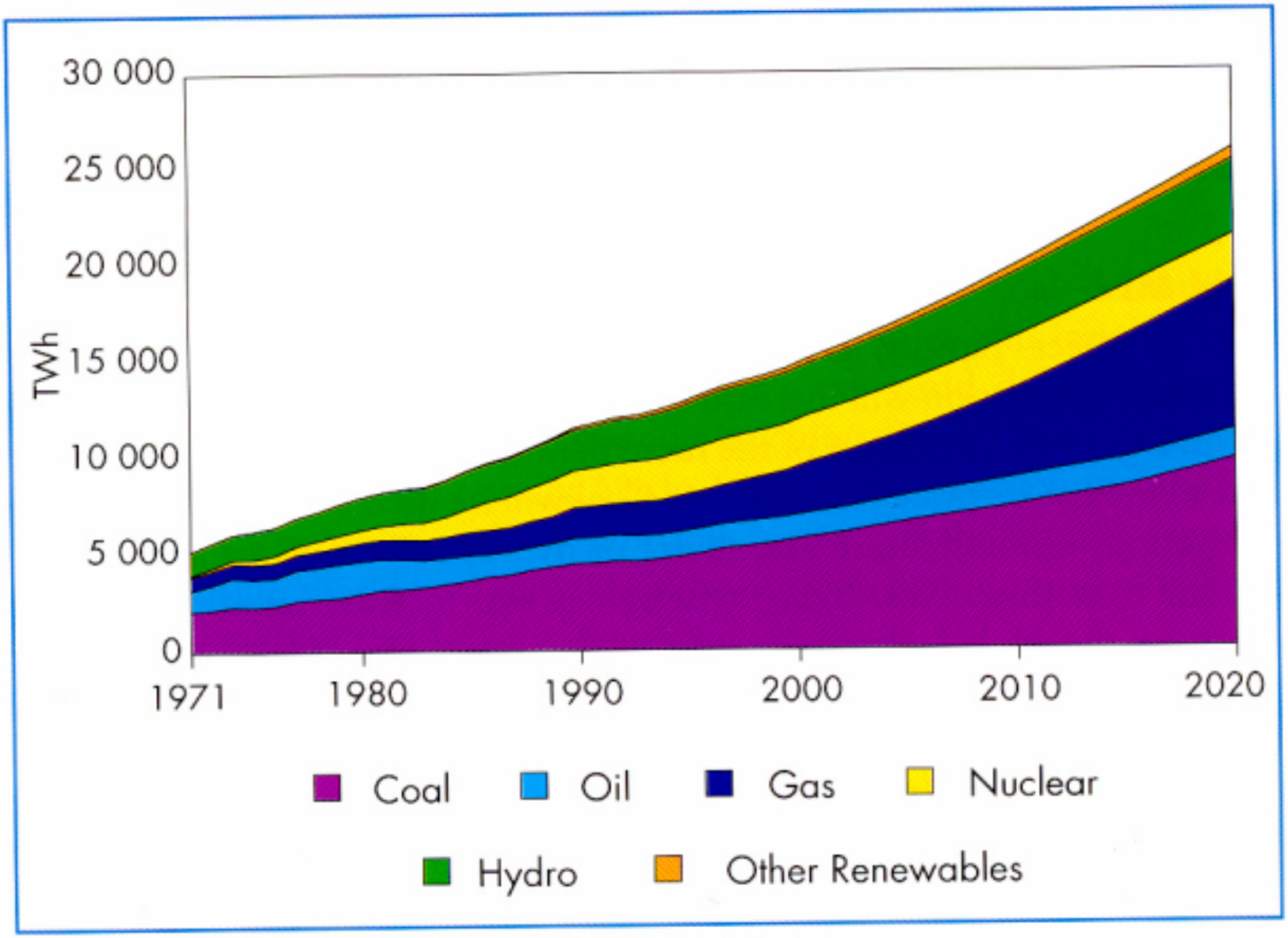
- CO_2 emissions in the Power Sector are highly dependent on the generation mode :
  - Coal : 920 kg/MWh
  - Oil : 683 kg/MWh
  - Gas : 452 kg/MWh
  - Nuclear : a few kg/MWh
  - Hydrolic : 0 kg/MWh

- However the selection of the generation mode is today based on considerations other than CO_2 emissions :
  - investment cost $\Rightarrow$ gas
  - duration of construction $\Rightarrow$ gas
  - availability of resources $\Rightarrow$ coal
  - acceptance by public $\not\Rightarrow$ nuclear

- CO_2 emissions are ignored because associated costs for the community are not internalized.

World Electricity generation 1971-2020 (IEA)

Figure 3.9: **World Electricity Generation, 1971-2020**



CO_2 emissions in 2020

- According to the “Reference Scenario” of IEA
  - annual global CO_2 emissions from electricity generation will increase by 76% between 1997 and 2020 and represent 37 % of the total CO_2 emissions in 2020 (13500 Mt i.e. more than 50% of the actual total emissions),
  - more than 2/3 of incremental CO_2 emissions will be located in developing countries (China and India) notably due to growth in coal combustion.

CO_2 emissions in 2020

- THESE FORECASTS ARE VERY FAR FROM THE OBJECTIVE OF STABILIZATION RESULTING FROM THE KYOTO PROTOCOL.

- THEY PUT THE COMING DECADES AT RISK.

IS IT POSSIBLE TO BE MORE AGRESSIVE ?.

Limit the emissions : an absolute necessity

- Improve the efficiency (producers and users),
- Switch to less carbon intensive fossil fuels,
- Develop fuel cells,
- Use renewable energies.

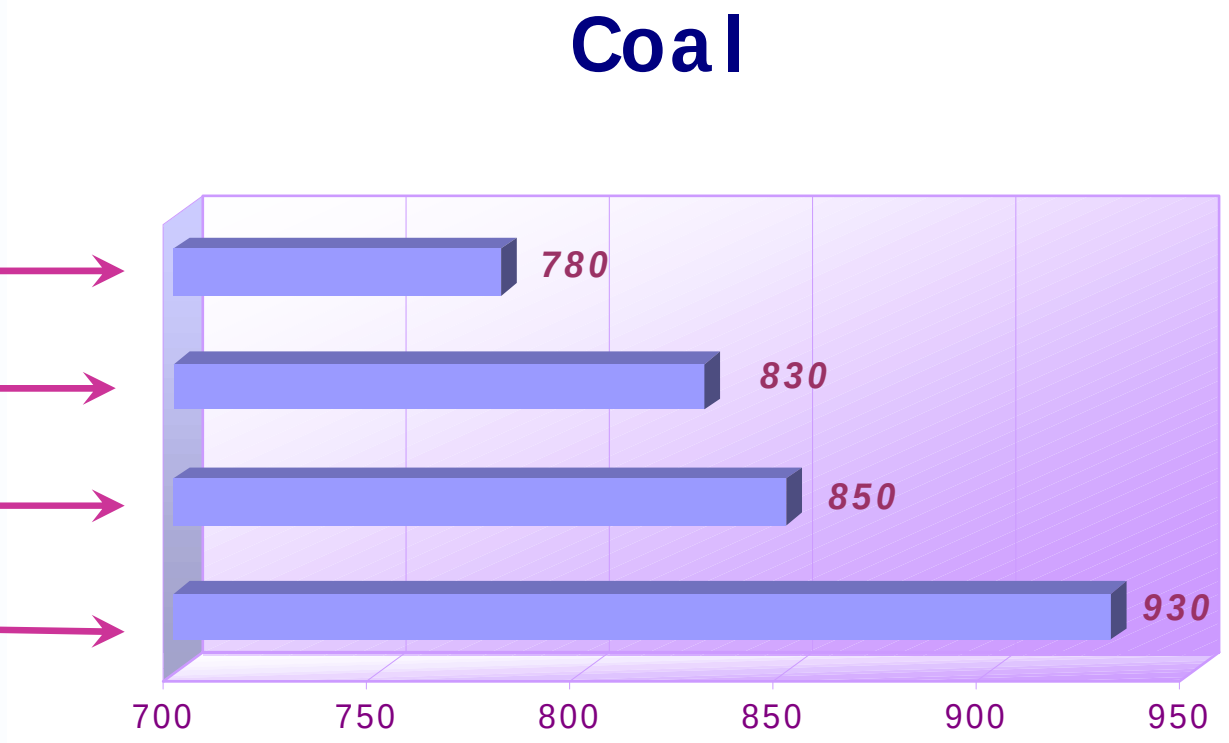
Improve the efficiency

IGCC (Integrated Gasification Combined Cycles)

PFBC (Pressurised Fluidized Bed Combustion)

Advanced PCF

PCF (Pulverized Coal Fired with Flue Gas Desulfurisation)



Average emissions in kg CO_2 / Mwh

Switch from coal to natural gas

- Maintaining coal-fired power plants at their 1977 level and substituting natural gas-fired generation to the new ones would reduce CO_2 emissions by about 10% in 2020 (1300 Million tons).
- The increase from 1997 to 2020 would remain close to 55 %.
- The dependency of electricity generation on natural gas would become very high (about 50%).

Develop fuel cells

Type	System Power	gCO2 /kWh
Methane-fuelled PEM (Proton Exchange Membrane)	≅ 200 kW	535
SOFC (Solid Oxide Fuel Cell)	≅ 50 kW	400 - 440
SOFC + GT (Gas Turbine)	≅ 500 kW	280 - 305
Methanol - fuelled PEM (with reformer)	≅ 100 kW	≅ 700
DMFC (Diret Methanol Fuel Cell)	≅ 100 kW	600

NB : Fuel Cell / microturbine system on co-generation

PEM ≅ 255 g CO_2 / kWh

SOFC ≅ 235 g CO_2 / kWh

Use renewable energies

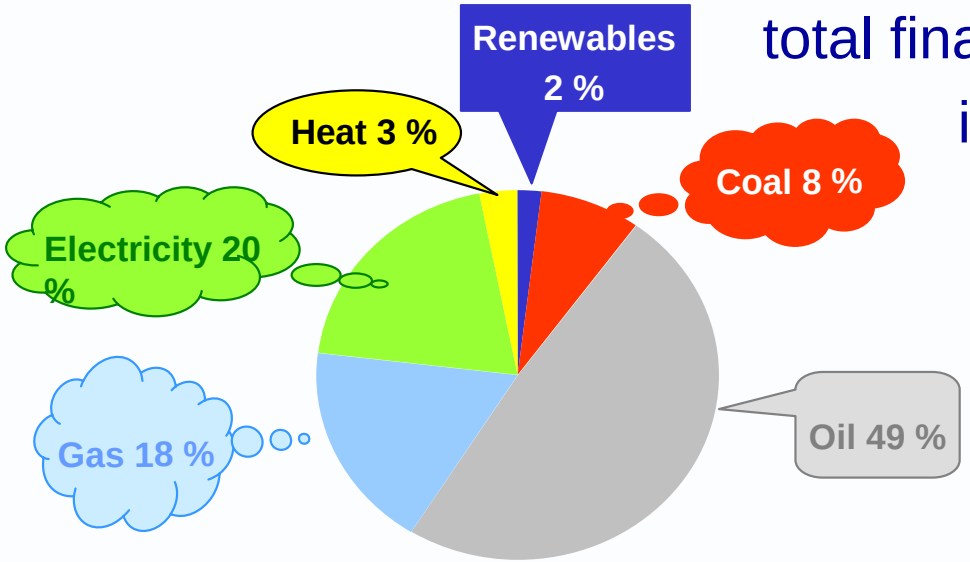
- Wind energy

- Solar Energy

- Hydro energy

But renewable have some limitations

Fuel shares in the world total final consumption in 2020



(Source IAE)

- Limitation will not be sufficient in the long term.

- More drastic measures are required :
  - rehabilitation of nuclear energy
  - capture and storage of CO_2

- They have to be prepared now.

Nuclear energy

- By generating electricity with no CO_2 emissions, nuclear energy could contribute significantly to reducing greenhouse gas emissions.

- A 25% share of nuclear power of in the global electricity output (17% in 1997) would reduce CO_2 emissions by about 3000 Million tonnes in 2020 and more in the to follow decades.

Nuclear energy

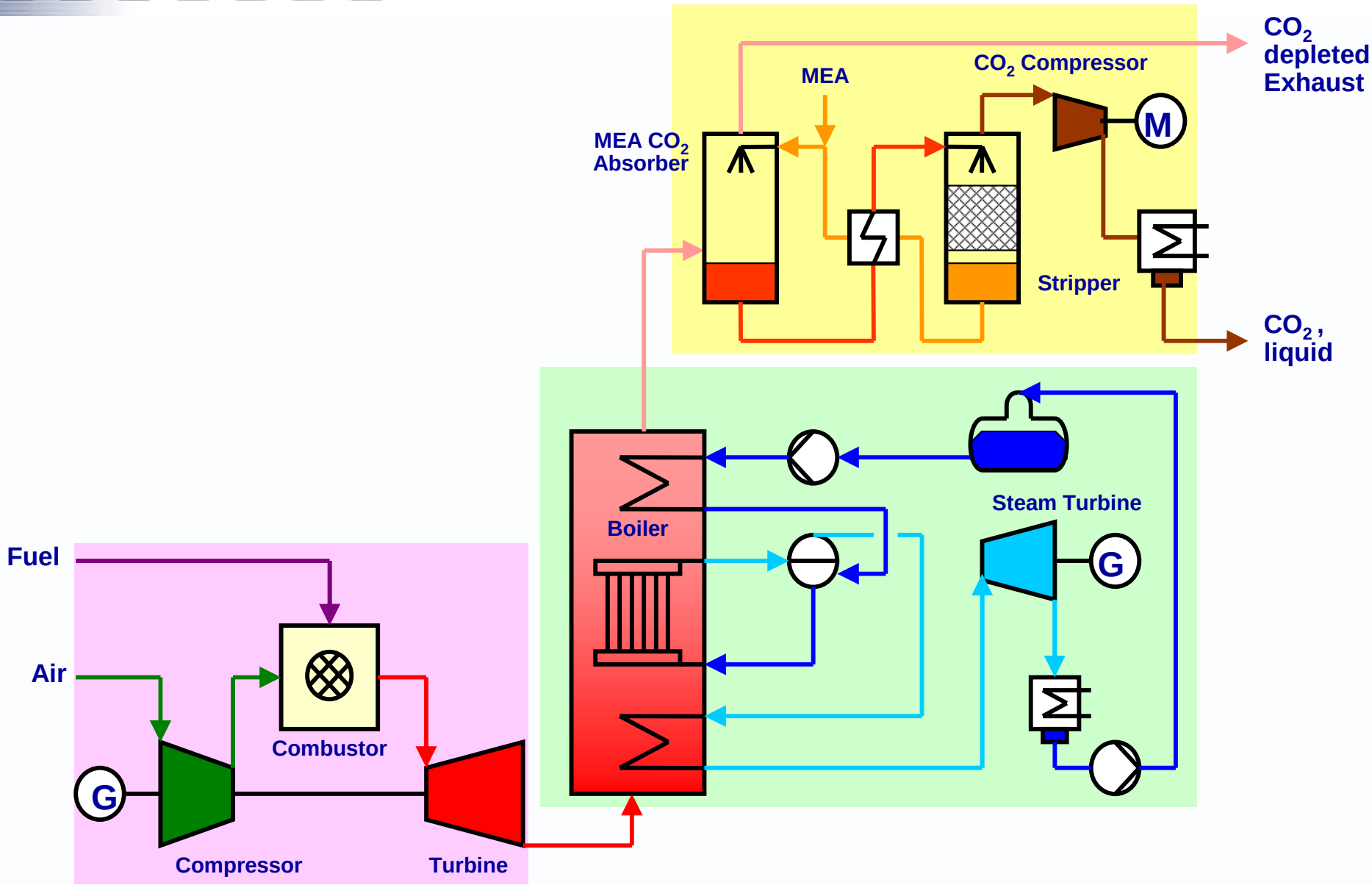
- This would imply :
  - a strong political involvement for restoring public confidence in this form of energy,
  - new developments aiming to develop smaller and safer reactors with an appropriate international control on proliferation.

However,nuclear energy cannot be the only solution to the CO_2 challenge.

CO_2 capture and storage

- Capture and storage of CO_2 will become indispensable in the next decades.
- Various technologies are today under investigation :
  - fuel decarbonisation prior to combustion,
  - “tail-end” capture solution (e.g. : amine scrubbing),
  - combustion in O_2 / CO_2 / H_2O atmospheres
    - CO_2 cycles with cryo air separation
    - air turbines with integrated membranes.

Example : Conventional GTCC with MEA CO_2 - Absorber



CO_2 capture and storage

These technologies cannot be considered as mature :

- they significantly deteriorate the efficiency (up to 10 points),
- they increase the cost of electricity,
- they require a large investment effort.

CO_2 capture and storage costs

Costs	PCF (Pulverised Coal-Fired)	IGCC (Integrated Gasification-Combined Cycle)	NGCC (Natural Gas-Combined Cycle)
Cost increase of electricity generation (€ c/kWh)	≅ 2,5	≅ 3,1	≅ 1
Cost of CO_2 avoidance (€/ t CO_2)	50-75	45-60	35-55

Based on current technologies, the relative increase in the electricity cost would be between 20% to 90%.

CO_2 sequestration (capture, separation and storage)

- About 3000 GW of additional capacity will be built over the next 25 years, i.e. 120 GW per year.
- Assuming that 50% of the new fleet would be equipped with CO_2 capture systems, this would imply, under today's conditions, an additional investment of about 50 billion € per year.

CO_2 sequestration (capture, separation and storage)

- Such an investment justifies an R&D effort much higher than the current one. Opportunities for significant cost reductions exist since very little R&D has been devoted to CO_2 capture technologies.

The US DOE estimates that $ 60 M per year for 10 years should be spent on R&D in CO_2 sequestration

Creating the appropriate economic context

- Nothing will happen if the players in the economy are not encouraged to be proactive.
- CO_2 is not a pollutant. Only excess of CO_2 may be hazardous. A lump-tax would do nothing except jeopardize the economic growth.
- More subtle mechanisms must be implemented :
  - CO_2 allowances trading associated with emission credits,
  - contractual commitments.

Infringements on the obligations should trigger sufficiently high penalties : 100 to 200 € per ton of CO_2

Conclusions

- Power generation will be a major issue in the coming decade as regards CO_2 emissions.
- Conventional approaches will not suffice to stabilise emissions
- Faced with this issue, two routes of an order of magnitude apportioned to the challenge present themselves :
  - rehabilitation of nuclear power,
  - sequestration of CO_2.
- An appropriate economic framework must be created to allow the right decisions to be taken.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