The Future of Fusion

Presentation to the VLT Meeting

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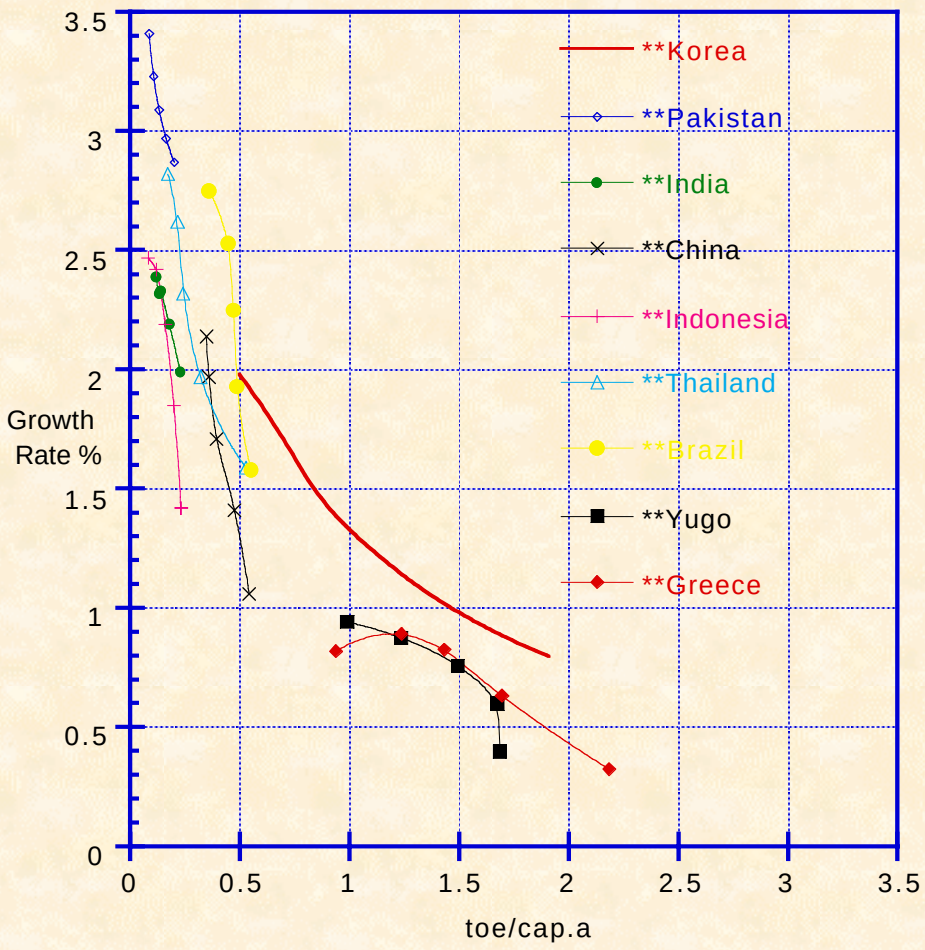
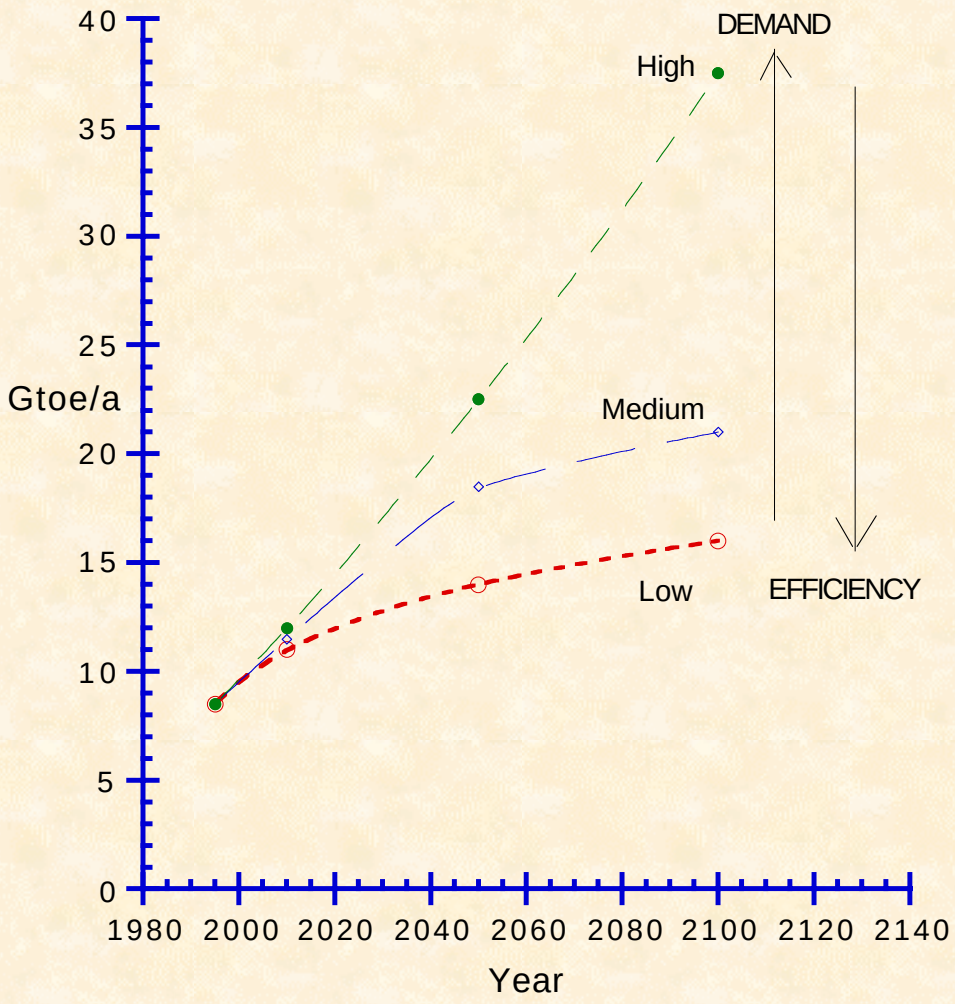
Population Growth Rate versus Annual Energy per Capita for the Period 1965 to 1992.



Projections for energy demand: 1995-2100, IASA, IEA, IPCC, Holdren, Mitre, Sheffield.



ENERGY OPTIONS for years

~2050 **~2100**

(14,000 to 22,500Mtoe/a) to (16,000 to 37,500 Mtoe/a)

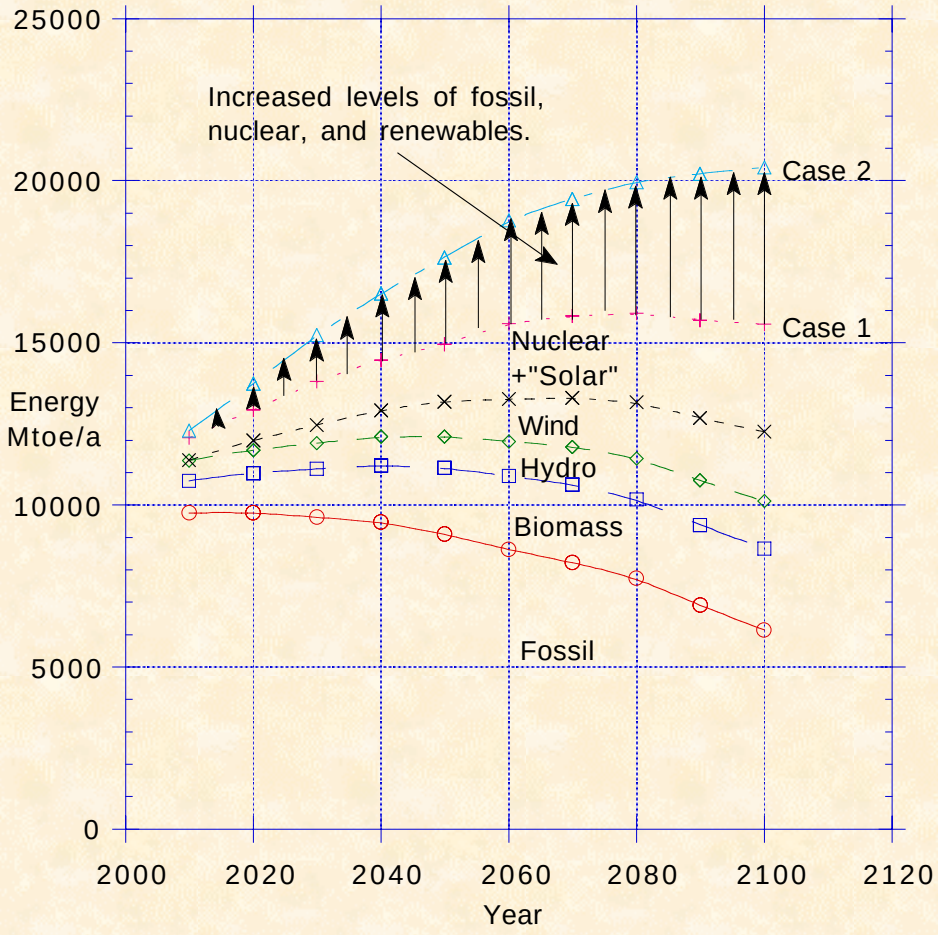
- **Continued improvement in efficiency**
  - Reduces energy demand e.g., by another third.

- **Fossil options**
  - Some increased level of sequestration seems likely.
  - Maintained or a slowly decreased use is a common scenario.
  - Increased use exacerbates problem of handling emissions and increases number of have-nots.

ENERGY OPTIONS (Conti.)

- **Nuclear energies**
  - Continued use or increase in fission energy requires a waste disposal solution.
  - Fusion energy may be a complementary source if developed.
  - Nuclear energies need to be handled internationally!
- **Renewable energies**
  - Opportunities for substantial solar and wind power deployment assuming economics and siting acceptable.
- **Hydrogen system**
  - Hydrogen can become the traded fuel source of choice.
  - Production from fossil fuels (with sequestration), from biomass and from electricity generally

Example energy sources: Cases 1and 2.



FUSION ENERGY PROJECTIONS

- Assume that the first power plants operate around 2050, probably in Japan or Europe.

- Build-up rates may be constrained by the energy pay-back time - up to 1.5 years for some reference designs -and by tritium build-up rates to support new plants for D-T systems.

- Assume a maximum doubling time of 5 years after the first plants have operated for a few years.

- Assume that plants are built and operated by international consortia so that they may provide energy in countries which do not have all of the skills needed in-house.

FUSION ENERGY PROJECTIONS (Conti.)

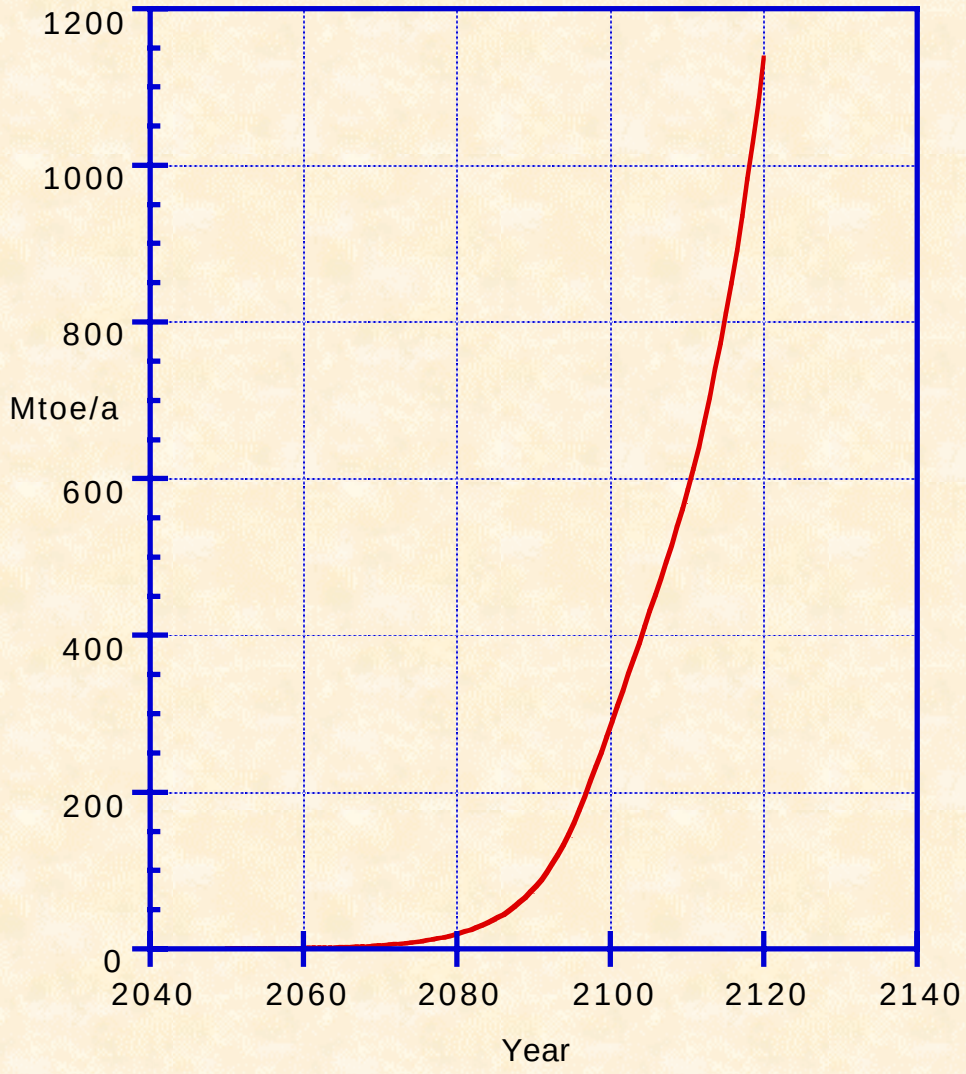
•For the example cases, the estimated fusion energy production (fossil fuel replacement value) is shown in the table.

•Fusion energy production (Mtoe/a) for 2100 and 2150.

Examples	2100	2150
Case 1	160	550
Case 2	310	600

Note that production of 100 Mtoe/a will require 180 fusion plants of 1,000 MW_e each operating with a 75% capacity factor.

Example Fusion Energy Build-up Scenario



Most Fusion Plant Designs Favor Large Size

- For fusion power plants at the 3 – 4 GWe scale, what are additional utility costs?
  Answer: around 5 mills/kWh.

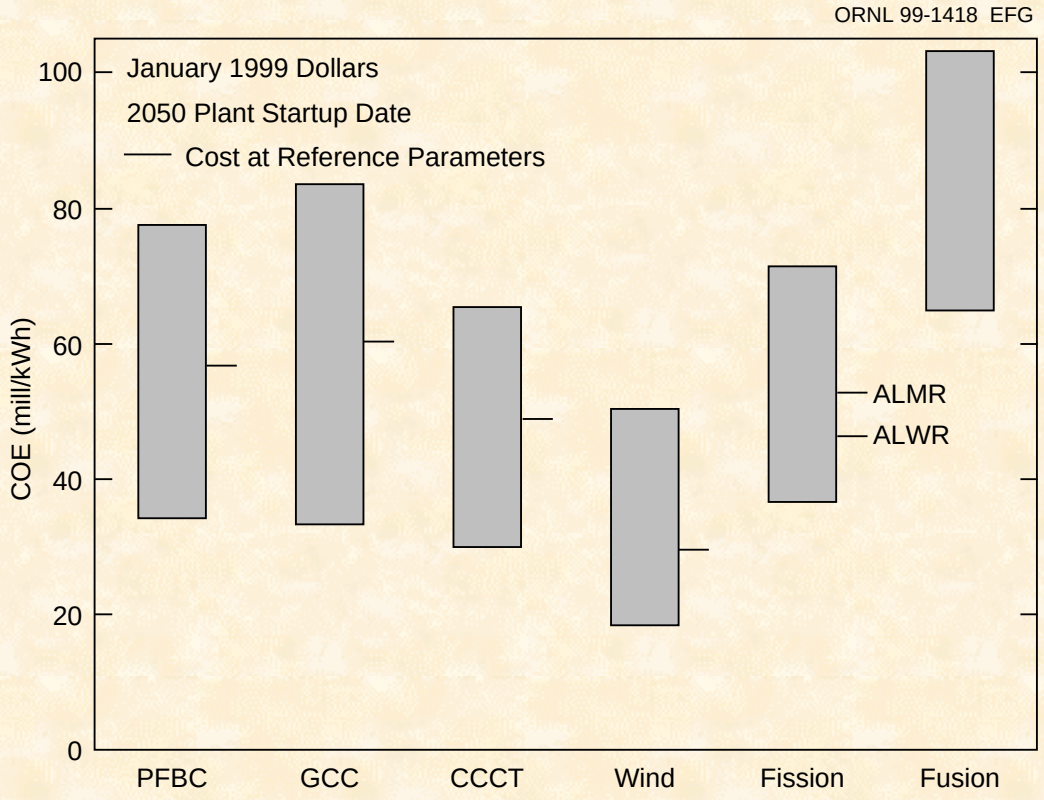
- If co-production of hydrogen is incorporated:

  - Could the hydrogen price be competitive with that from other sources?
    Answer: Yes, for off-peak generation.

  - Could some hydrogen be produced on-peak and still, overall, be cost competitive?
    Answer: Yes, at the 25% level.

  - Would such hydrogen production permit some electrical load following?
    Answer: Yes, with a response on the minute(s) time-scale.

Range of COE for concepts including carbon sequestration



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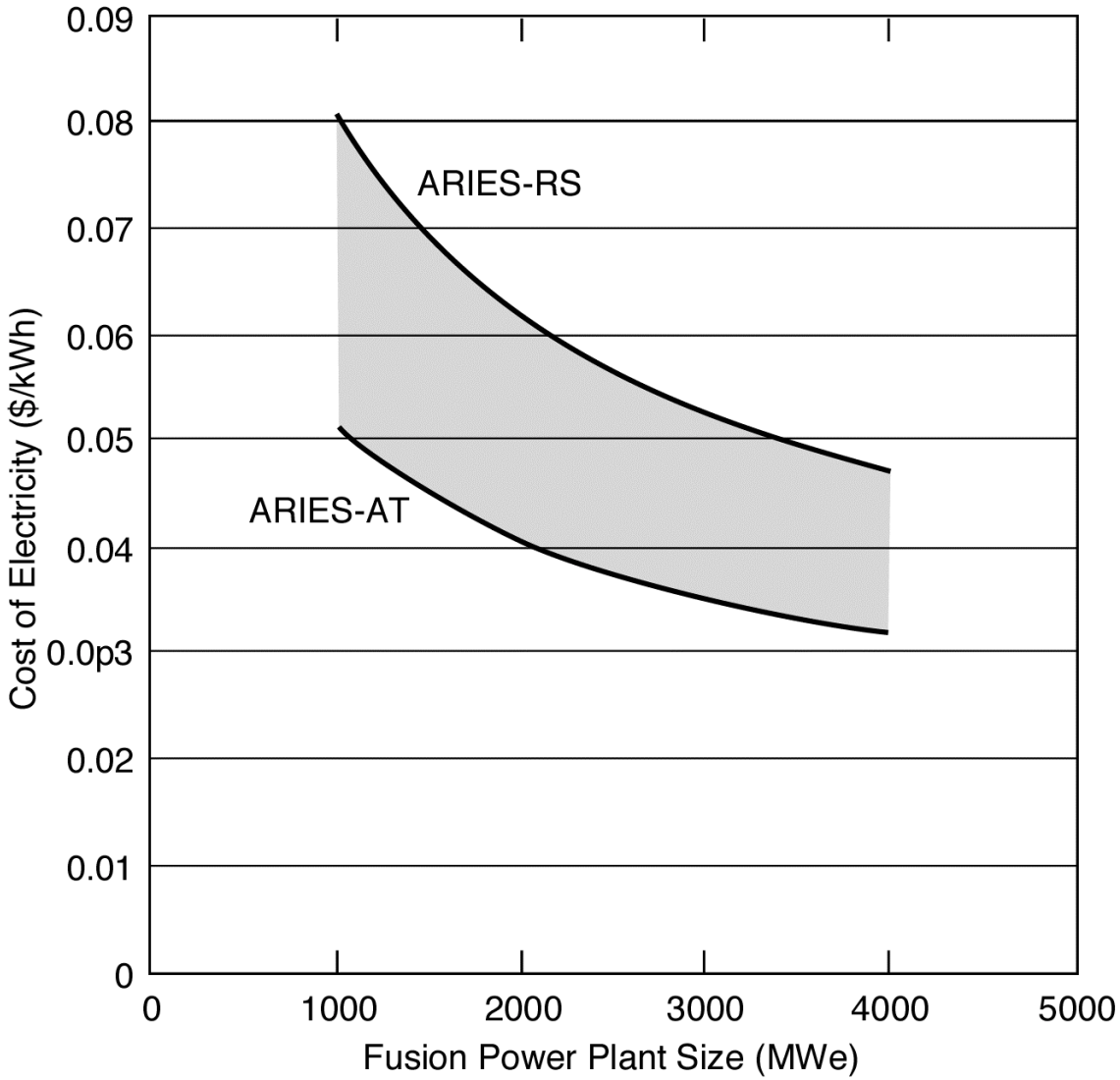
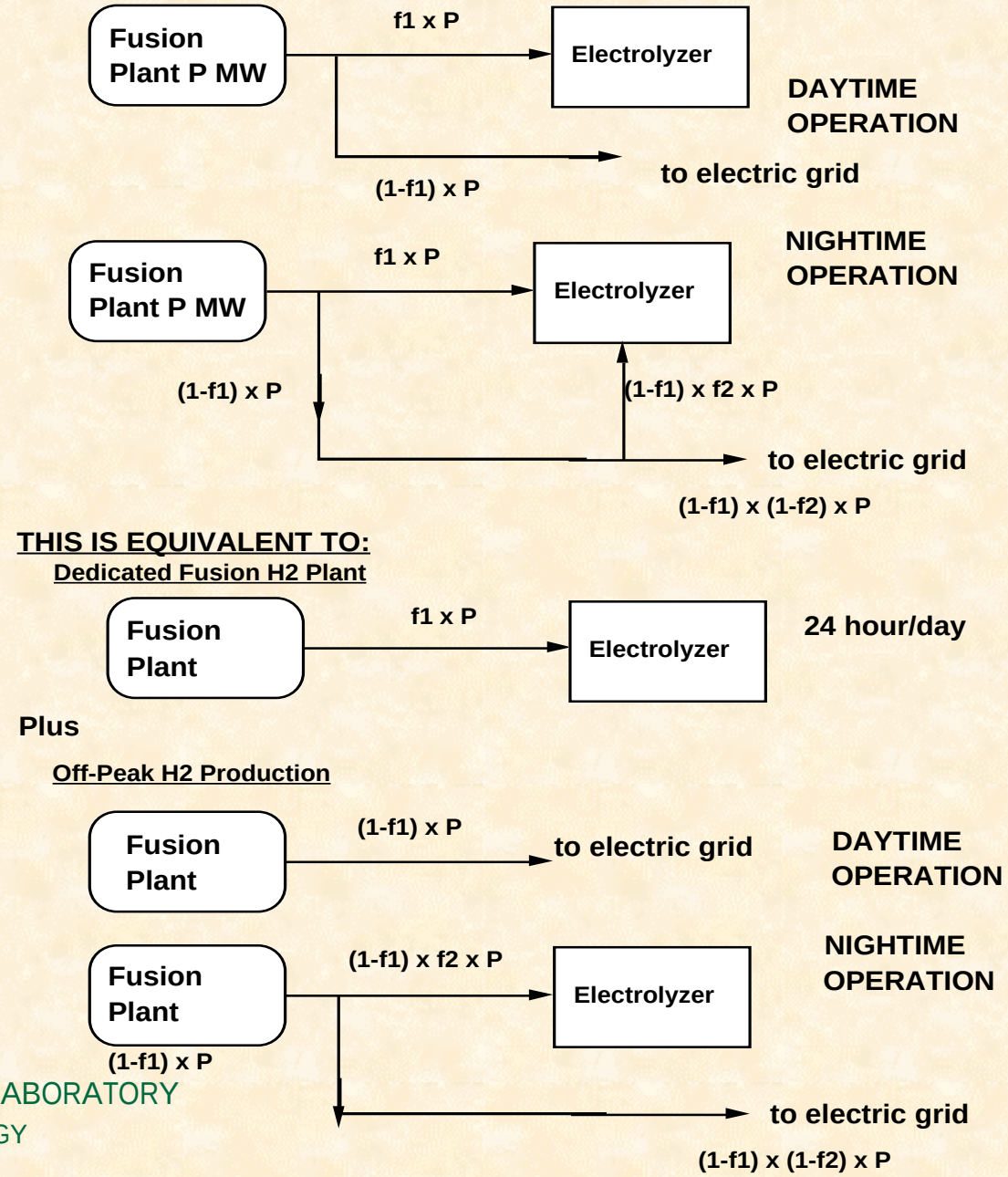
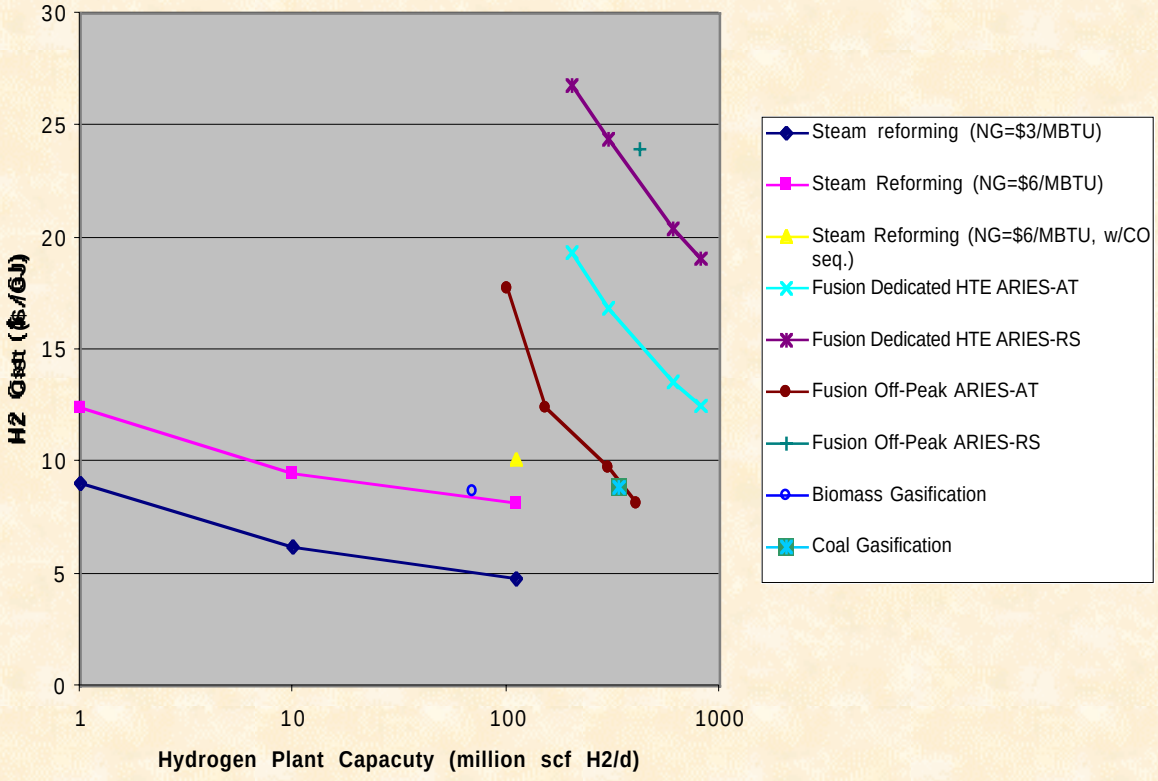
Projected Band for Costs of Fusion Electricity ($/kWh)



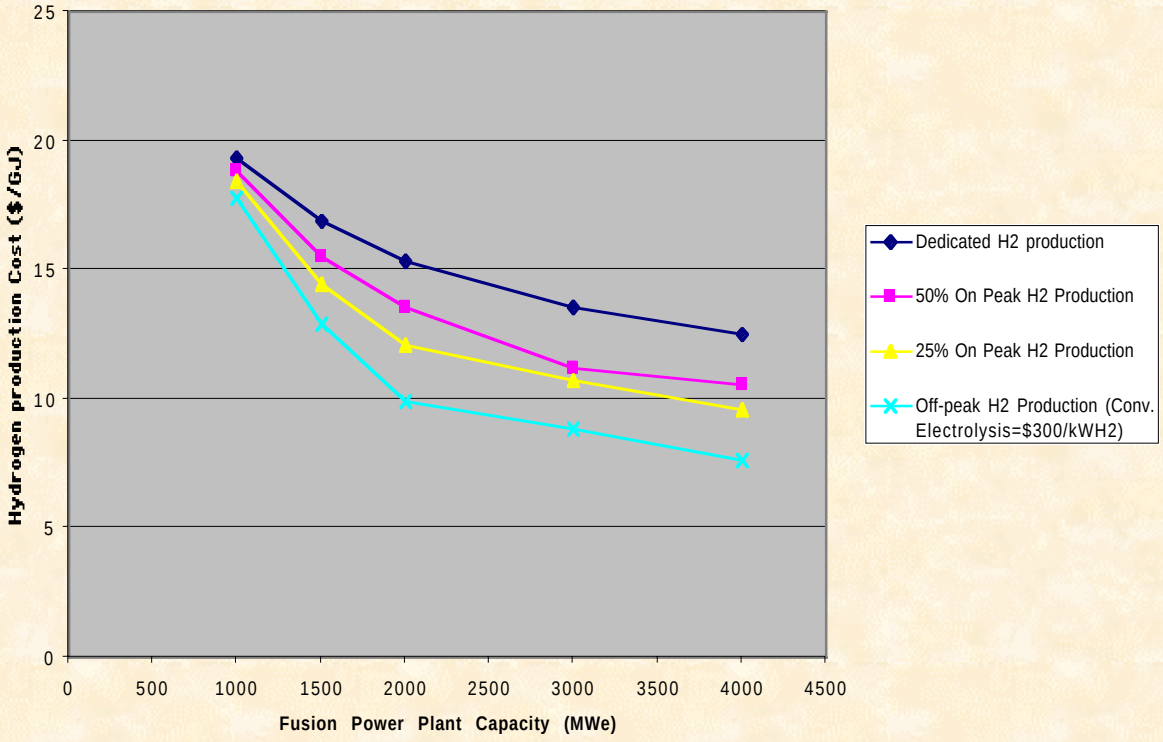
CONFIGURATION FOR PRODUCTION OF H2 DURING ON AND OFF PEAK HOURS



Cost of Hydrogen Production ($/GJ)



H2 Production Cost for Various Operating Strategies:
Dedicated H2 Production; 50% On-peak & 100% Off-peak H2 production;
25% On-Peak &100% Off-peak H2; Off-peak H2 Production Only
ARIES-AT , On-Peak Power Cost 6 cents/kWh, Conv.Electrolyzer $300/kWH2



CONCLUSIONS

- Increasing world population, 6 billion, rising to 9 to12 billion by 2100, and a need for increasing standards of living in the developing world will drive an increased energy demand - 2 to 3 times more by 2100.

- It will be necessary to supplement and, possibly, replace fossil fuels during this period, even with substantial improvements in the efficiency of energy use.

- A much greater use of nuclear and renewable energies will be required , even if carbon sequestration allows the continued high use of fossil fuels.

CONCLUSIONS (Conti.)

- Fusion energy could be available in the middle of the 21st century if ITER and NIF work and other technologies and radiation resistant materials are developed.

- Today's fusion power plant designs and the expected economies of scale for fusion plants indicate one route for fusion power to be competitive – going to large power plants e.g., 3 to 4 GWe.

- Studies show that even with the additional utility costs for such plants, about 5 mills/kWh, they should remain competitive. Co-produced hydrogen could be priced competitively, reduce the power going to the grid, and could allow load following while running at full power.