GTSP

Global Energy Technology Strategy Program

The Potential Role of Nuclear Power Technologies in a Global Energy System

GTSP Nuclear Deep Dive

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Operated by Battelle for the U.S. Department of Energy

Objective

- ❑ To provide a deeper understanding of the role of advanced nuclear reactor and fuel system technologies in the context of the global energy system and climate change issues.

I. Model Development
   - Nuclear system analytical capability

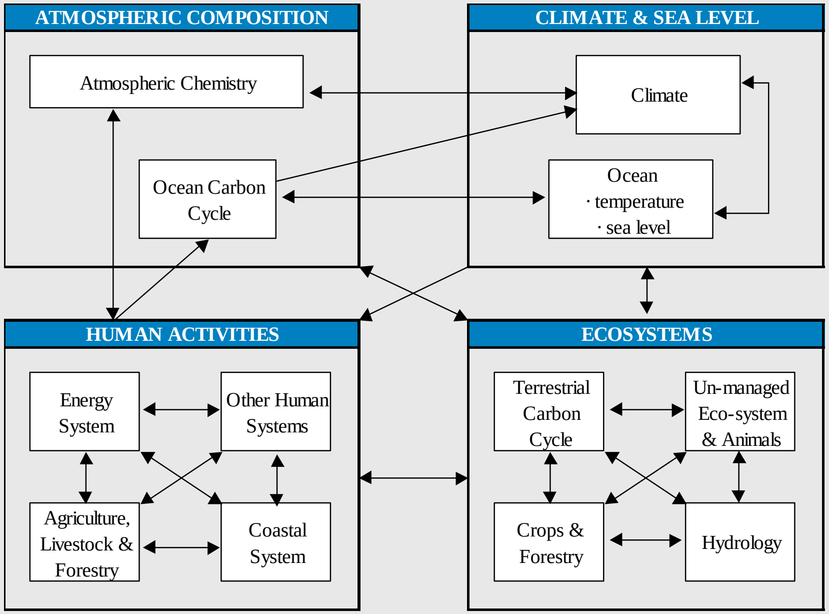
II. Analysis
   - How does the choice of nuclear fuel cycle and the cost of nuclear technologies affect the penetration of nuclear power?

Roadmap

- Model Development
- Assumptions
- Nuclear Energy in the Reference Scenario
- Fuel Cycle (Uranium vs. Plutonium)
- Nuclear Energy in the Carbon Policy Scenario
- Conclusions
- Future Studies

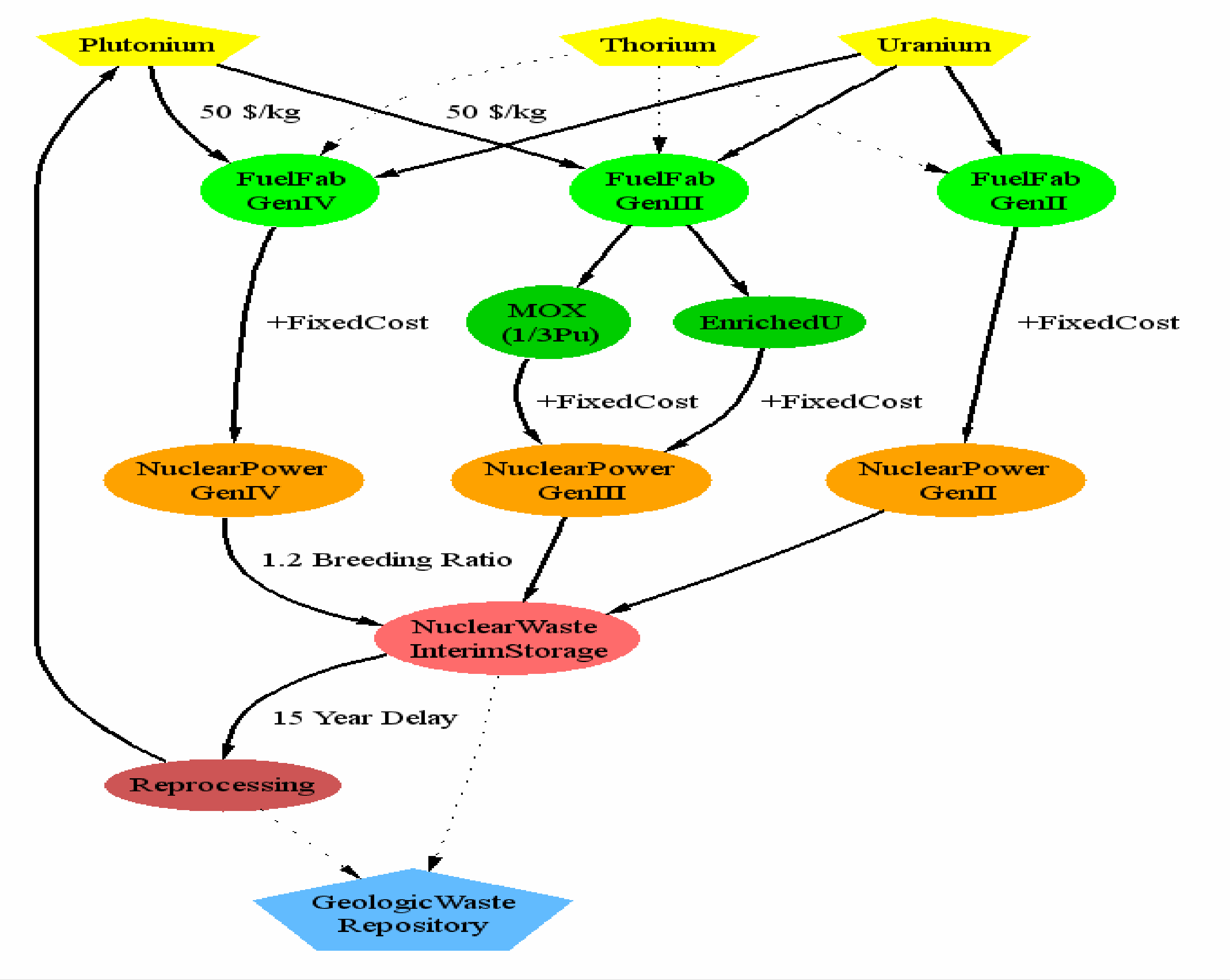
MiniCAM

- The nuclear sector analysis is embedded in the MiniCAM model—an integrated assessment modeling framework
  - Energy-Agriculture-Economy Market Equilibrium
  - 14 Global Regions
  - Explicit Energy Technologies
  - Fully Integrated Agriculture and Land Use Model
  - Key for consistent biomass crop analysis
  - Multiple Greenhouse Gases
  - Typically Runs to 2095 in 15-year time steps



O^bj^ECTS MiniCAM

Nuclear Energy System Modeling



Nuclear Reactor Definitions

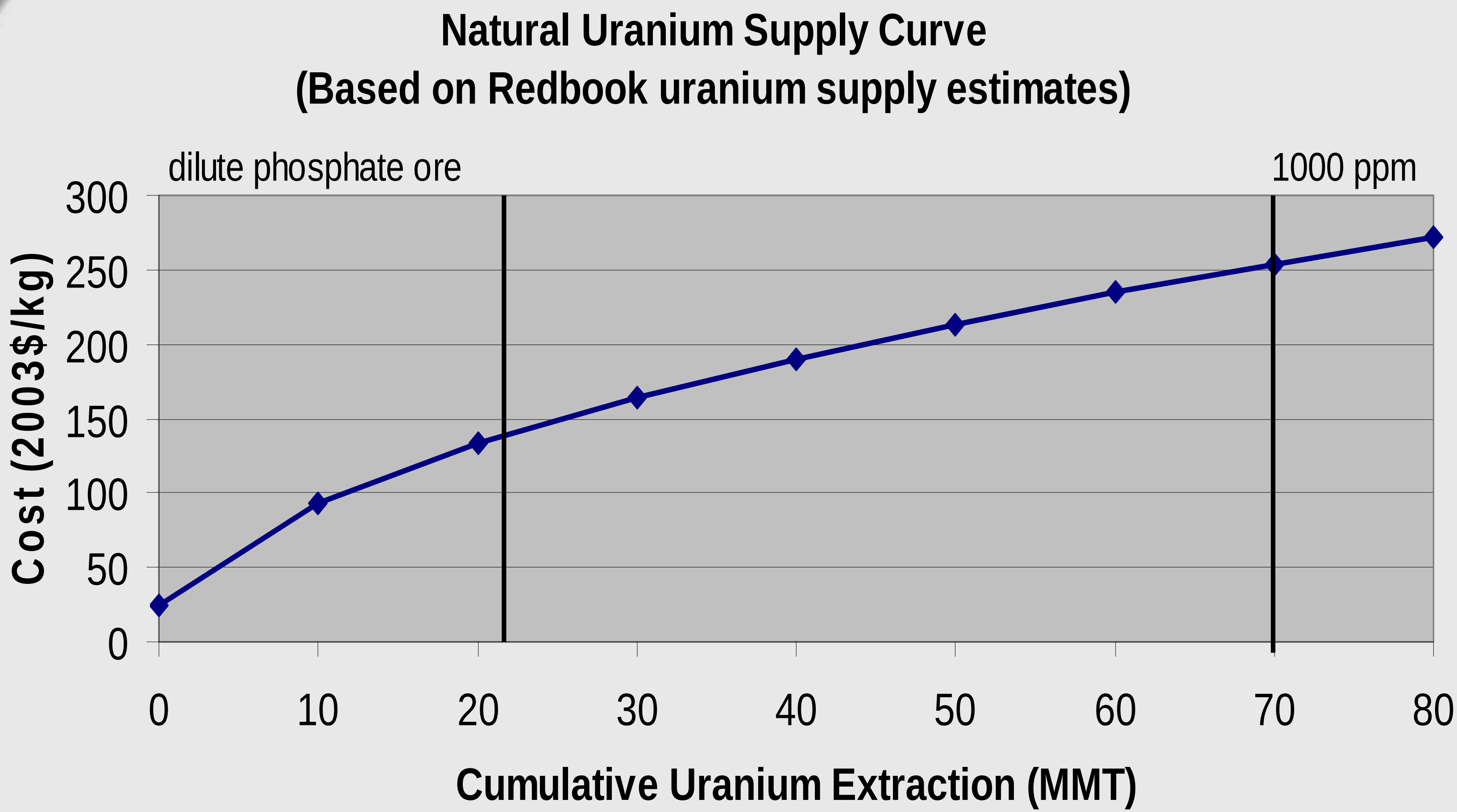
- Gen II
  - Conventional light water reactors with once through fuel cycle
- Gen III
  - Advanced light water reactors with more competitive and lower capital costs and higher efficiencies than Gen II
  - Few are currently deployed
  - Potential for fuel recycling
- Gen IV
  - Future reactor technologies that converts or breeds nuclear fuels
  - Eliminates concerns of natural fissile uranium limitations

Scenarios

- Nuclear technology cases
  1) Gen II only
  2) Gen III and Gen II (enriched U with once through fuel cycle)
  3) Gen III-MOX (fuel recycling) and Gen II
  4) Gen IV (breeders after 2035), Gen III and Gen II (enriched U and Pu recycling)
  5) Gen IV (breeders after 2035), Gen III-MOX and Gen II

- Under two policy scenarios
  1) Reference Scenario (no long-term climate policy)
  2) WRE 550 Scenario (550 ppmv CO_2 concentration)

Assumptions
The Natural Uranium Resource

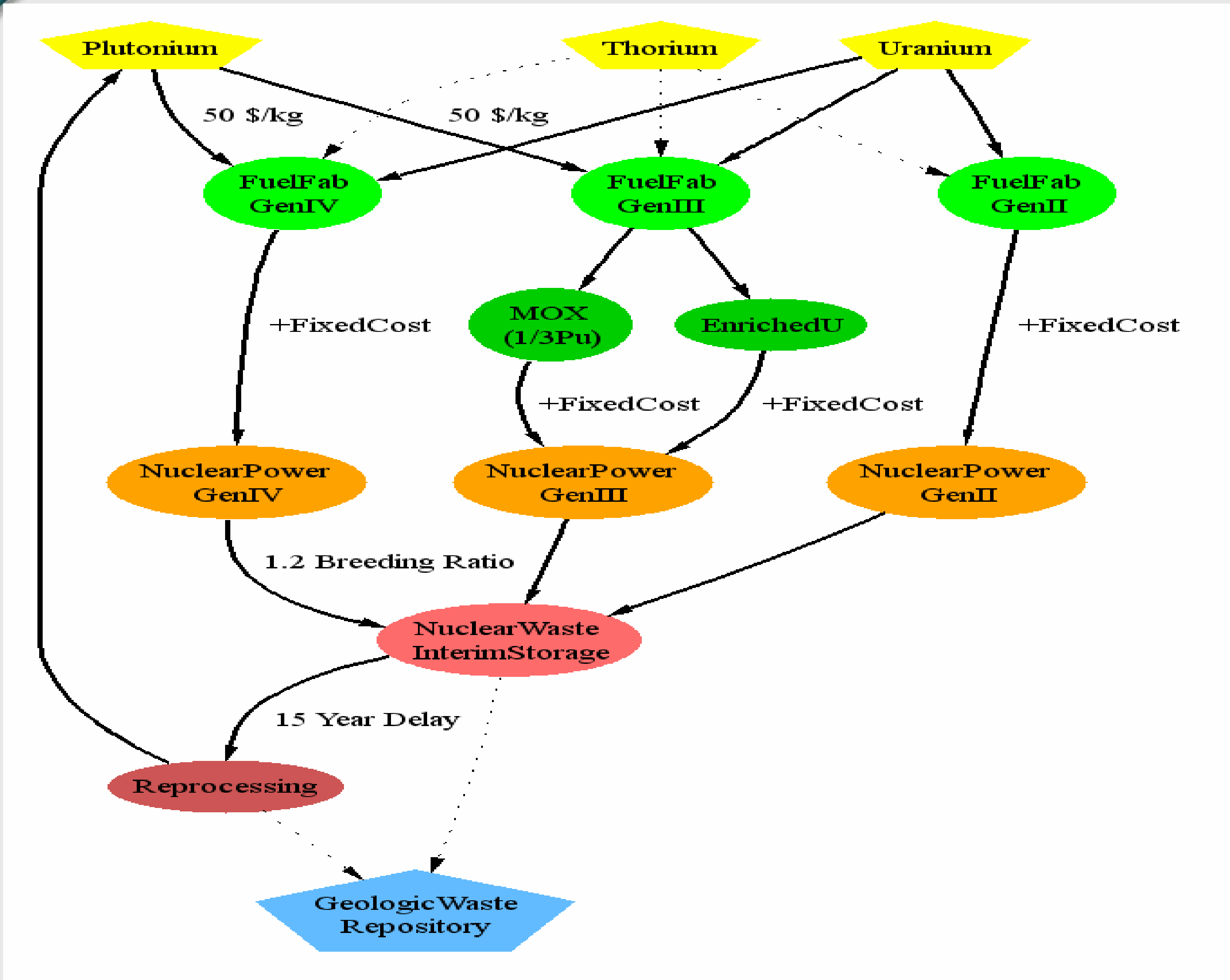


Assumptions
Nuclear Reactor Technology and Cost

Power Generation Type	Non-Energy Cost: Levelized Capital and O&M (2003 Cents/kWh)			
	2005	2020	2050	2095
NGCC	2.1	2.0	2.0	1.9
Coal	4.0	4.0	3.8	3.6
Gen II Nuclear	6.0	6.0	6.0	6.0
Gen III Nuclear		5.0	4.8	4.5
Gen IV Breeder Nuclear			4.8	4.5
Cost assumptions within the range of estimates from DOE EIA, University of Chicago, and MIT.				

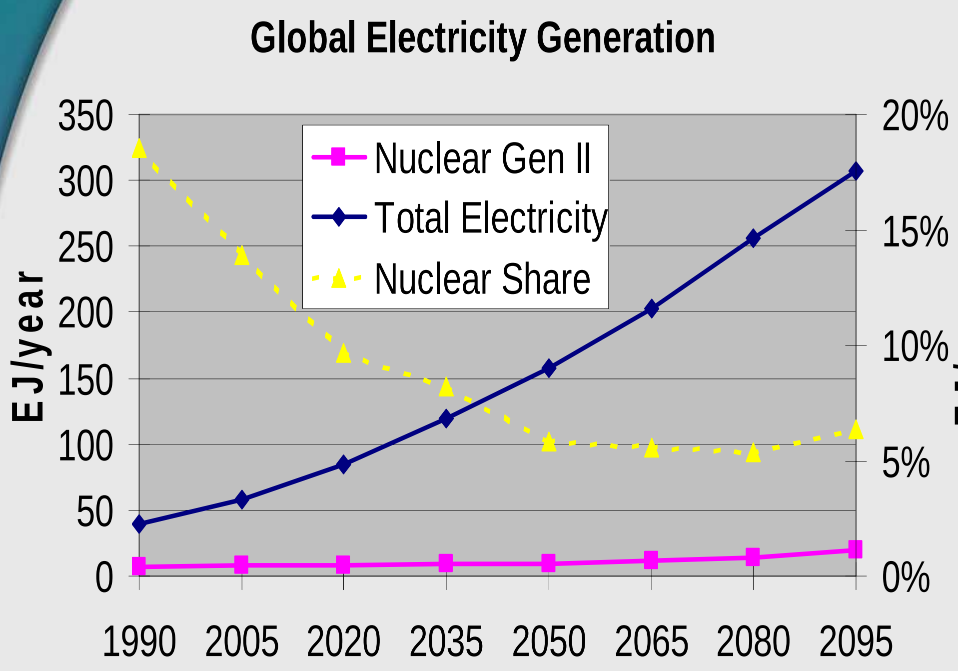
Comparison: The Economic Future of Nuclear Power, University of Chicago, 2004	
	2003 Cents/kWh
Legacy Nuclear	6.5 - 7.6
Pebble Bed Modular Rea	4.0 - 4.5
Coal	3.7 - 4.9
NGCC	3.5 - 4.0

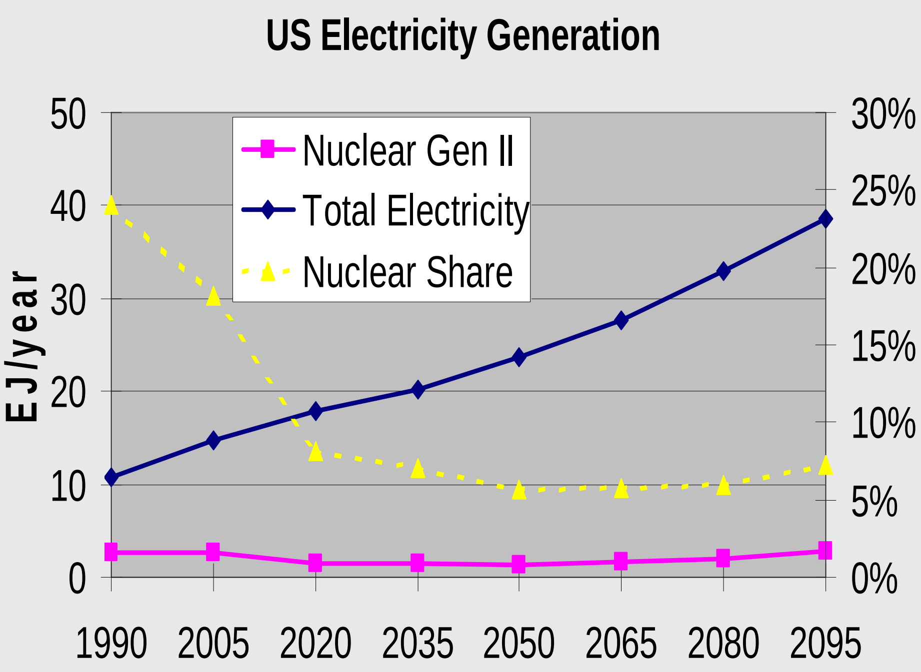
Assumptions: Nuclear Fuel and Fabrication Costs



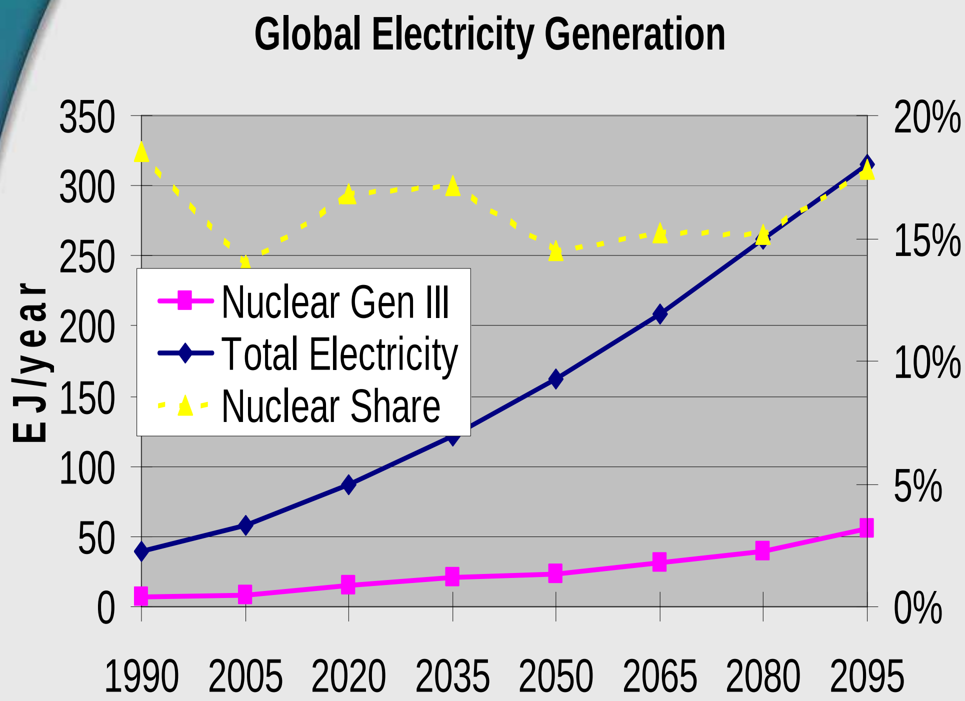
Reference Scenario: Gen II Nuclear Power

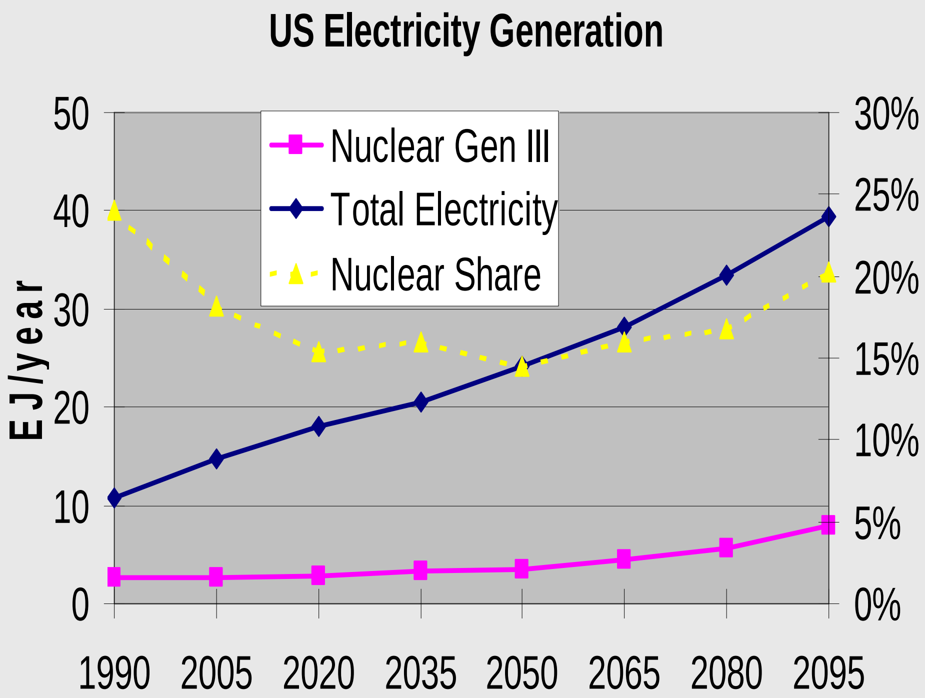
Conventional nuclear reactors are increasingly a smaller share of total generation





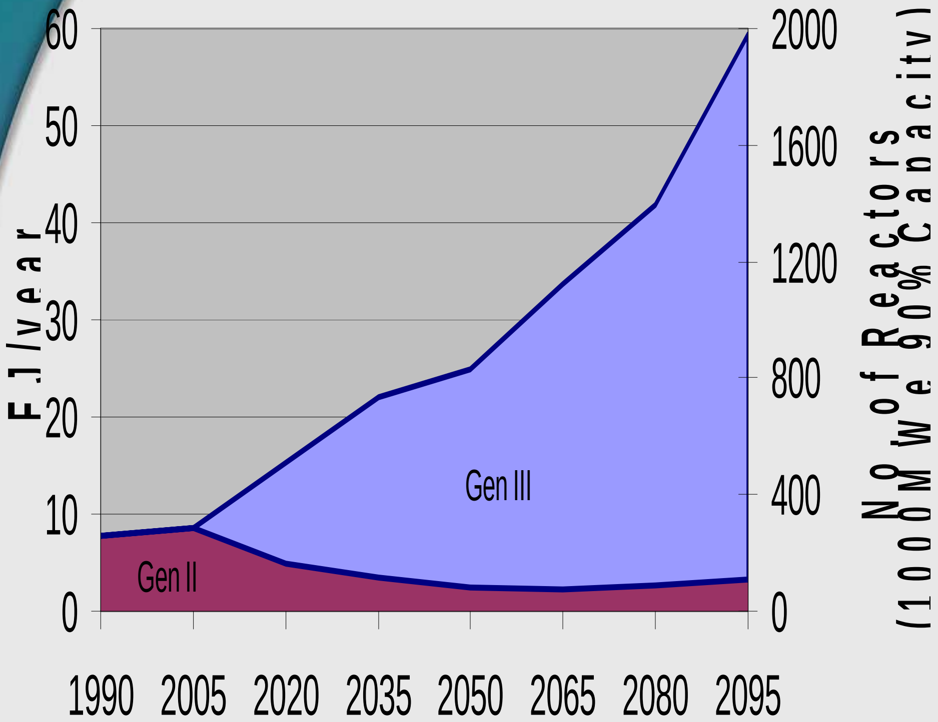
Reference Scenario: Gen III Nuclear Power (no recycling)



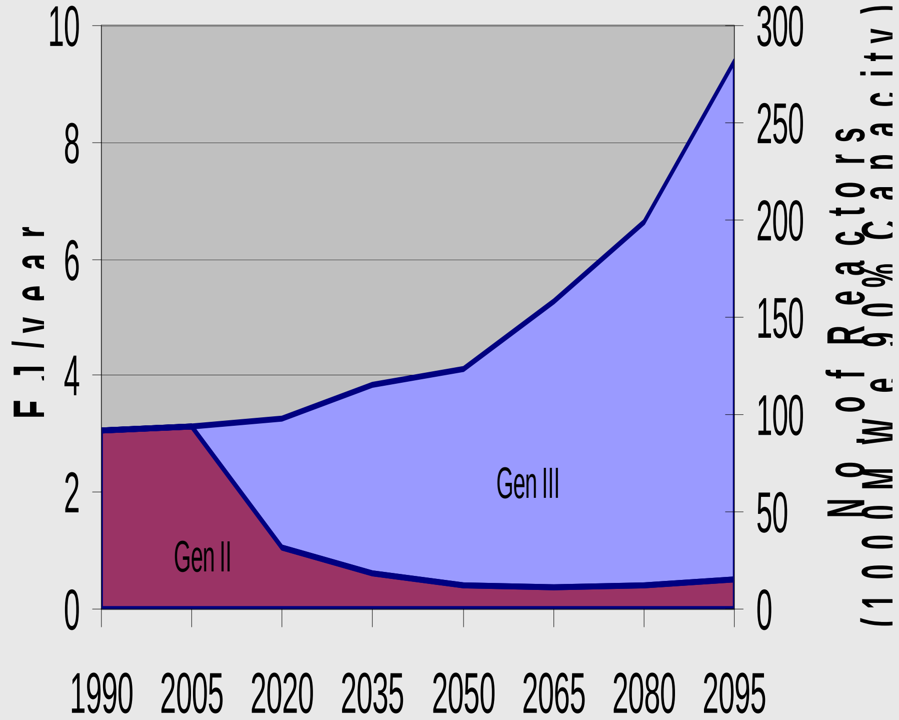


Reference Scenario: Gen III Nuclear Power (no recycling)

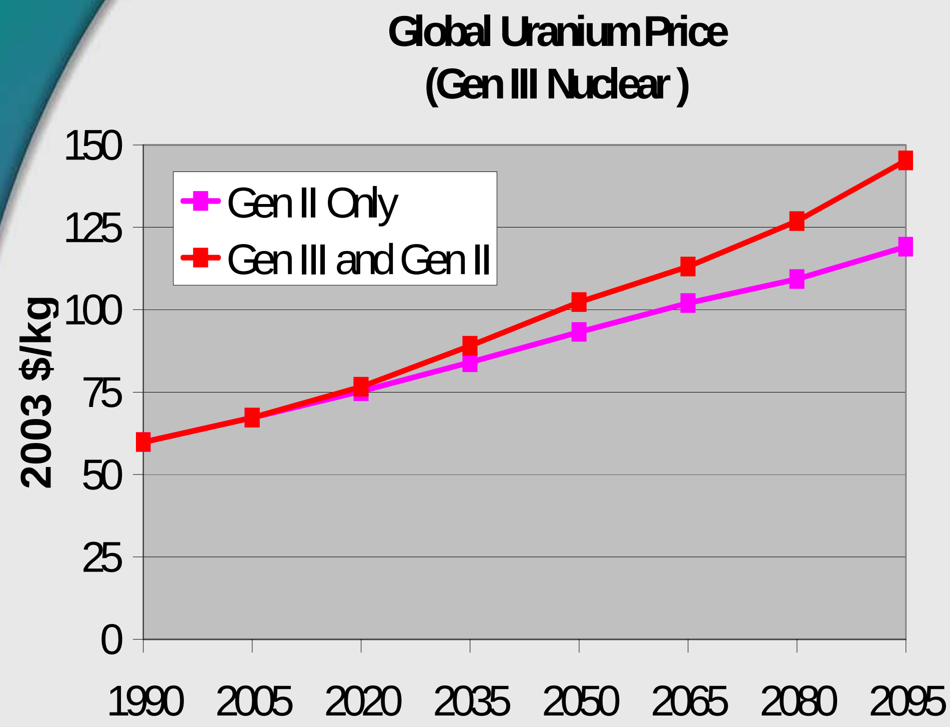
Global Nuclear Electricity Generation

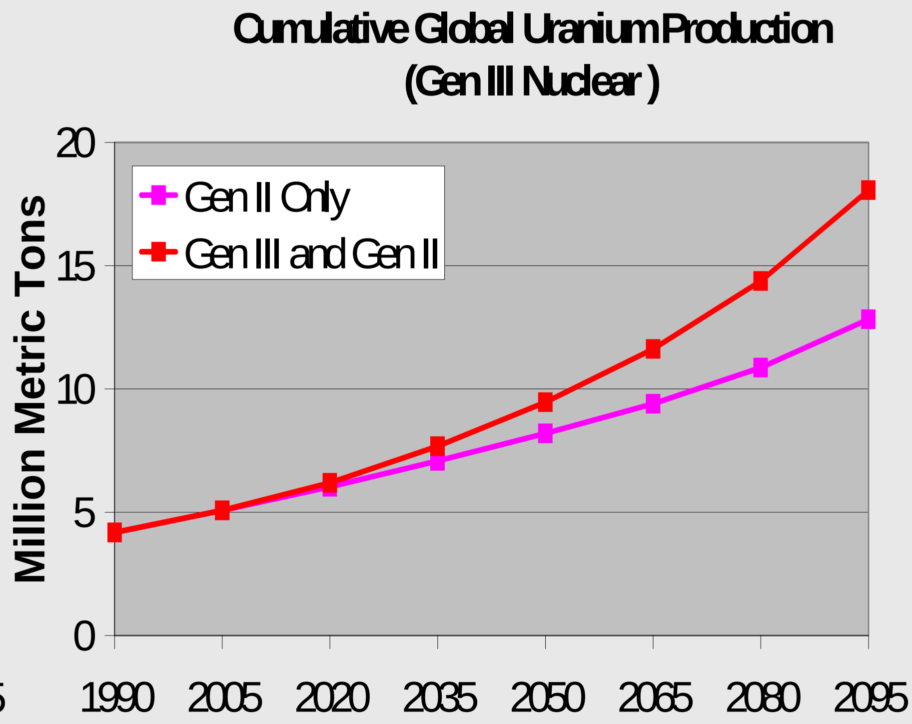


US Nuclear Electricity Generation

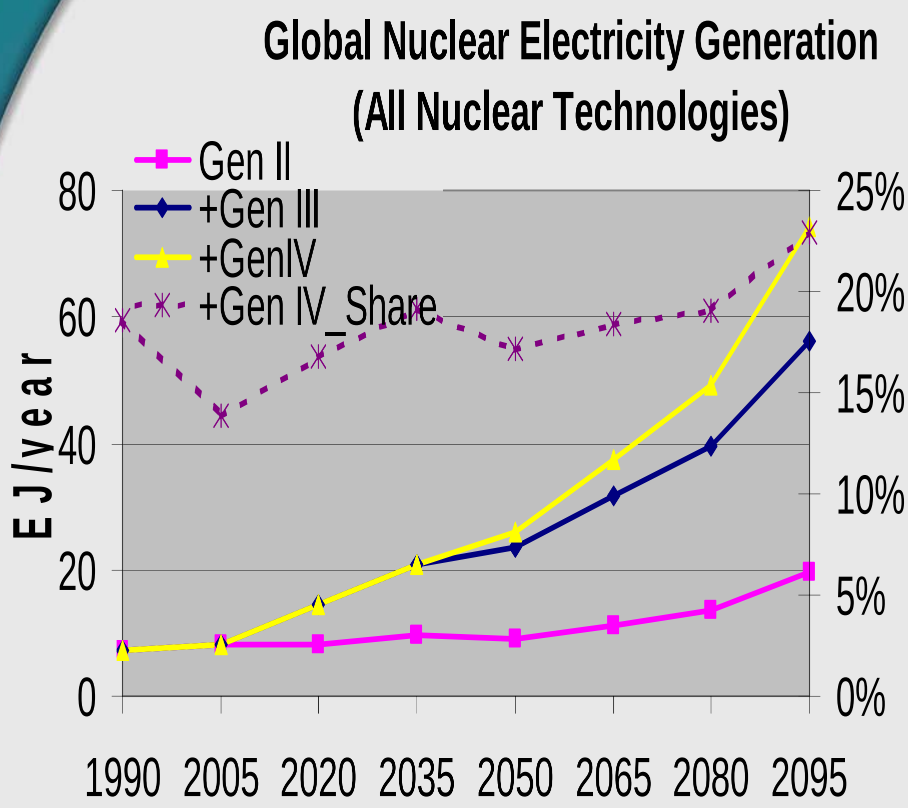


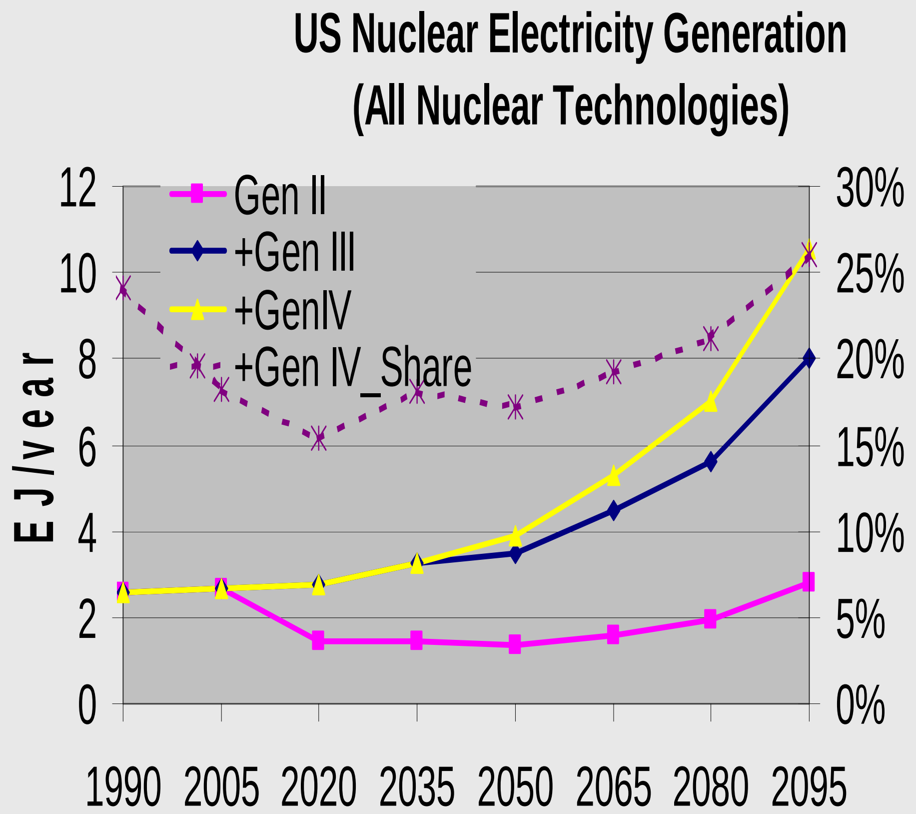
Reference Scenario: Gen III Nuclear Power (no recycling)



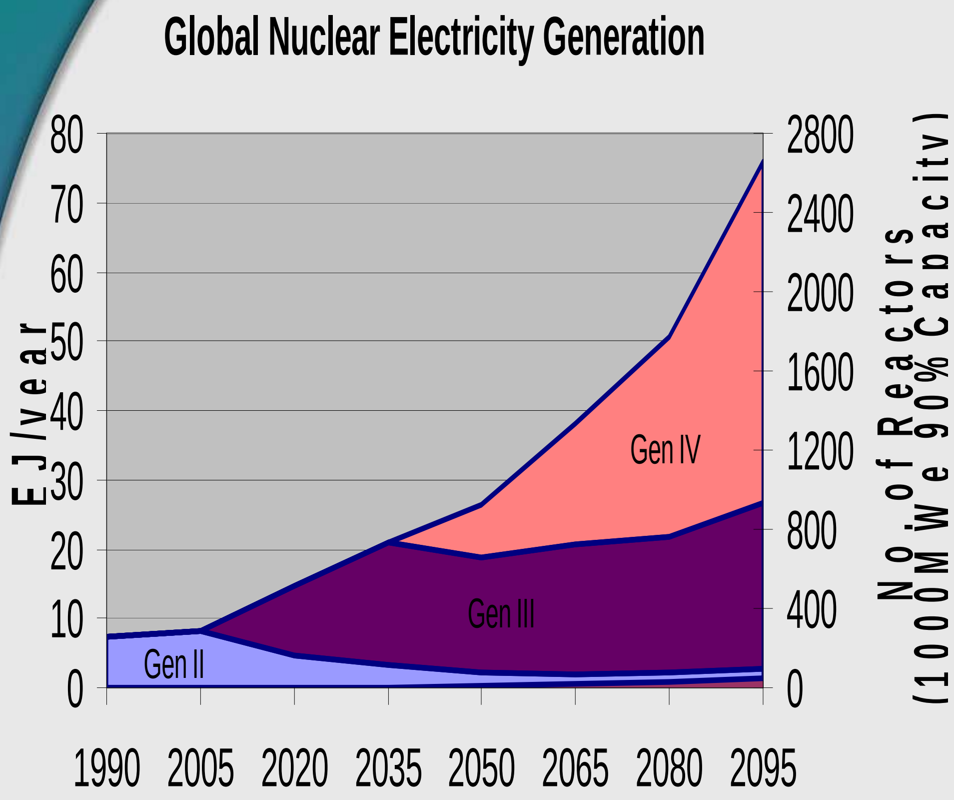


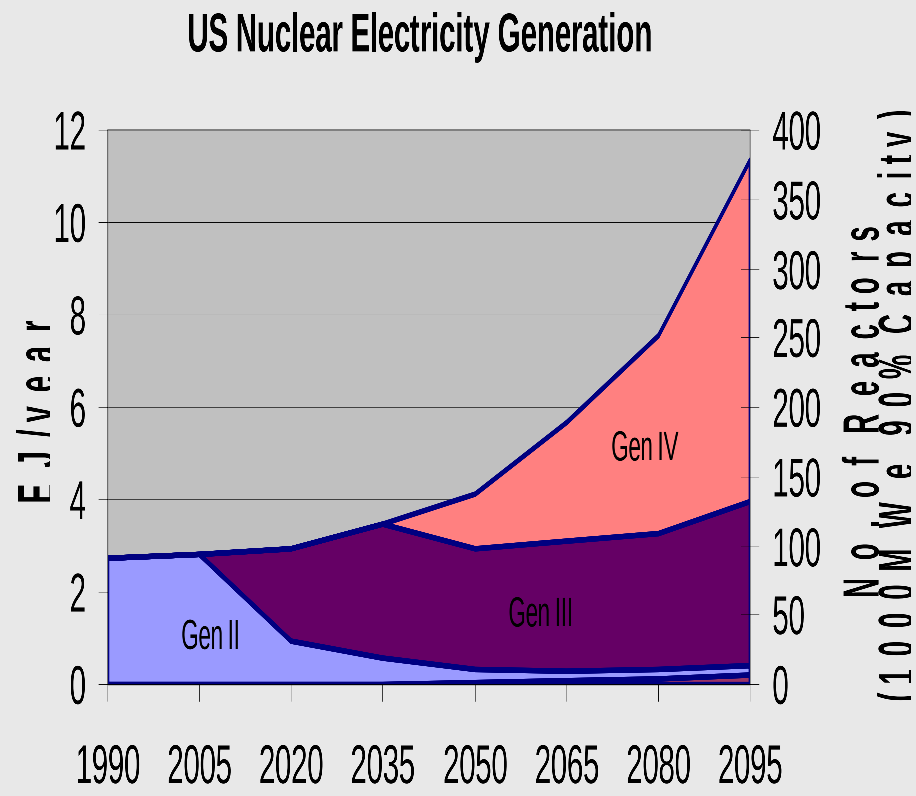
Reference Scenario: Gen IV Breeder Nuclear Power (Pu recycling)





Reference Scenario: Gen IV Breeder Nuclear Power (Pu recycling)





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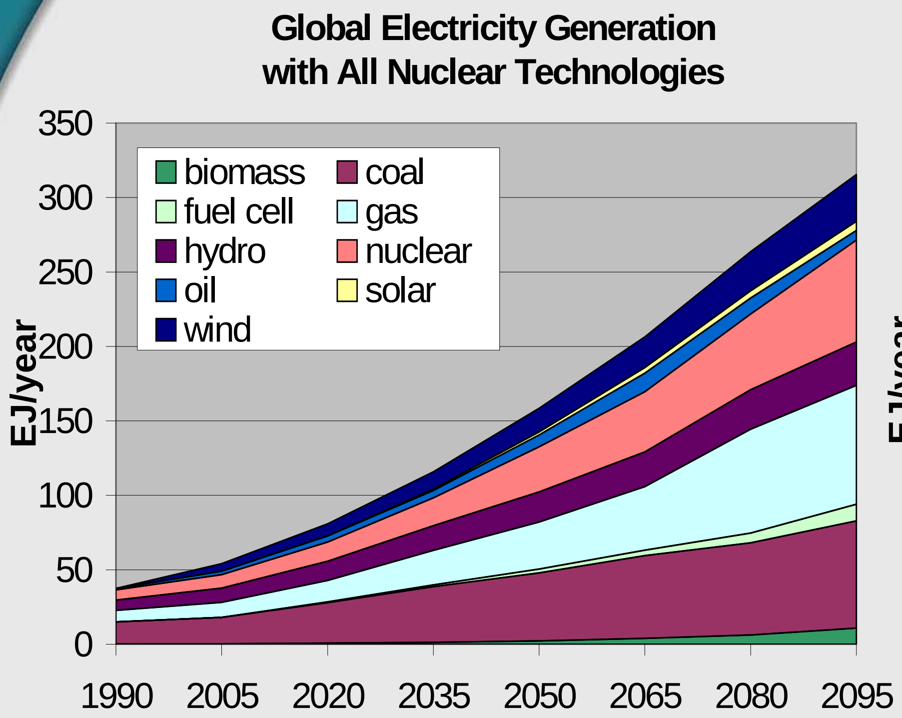
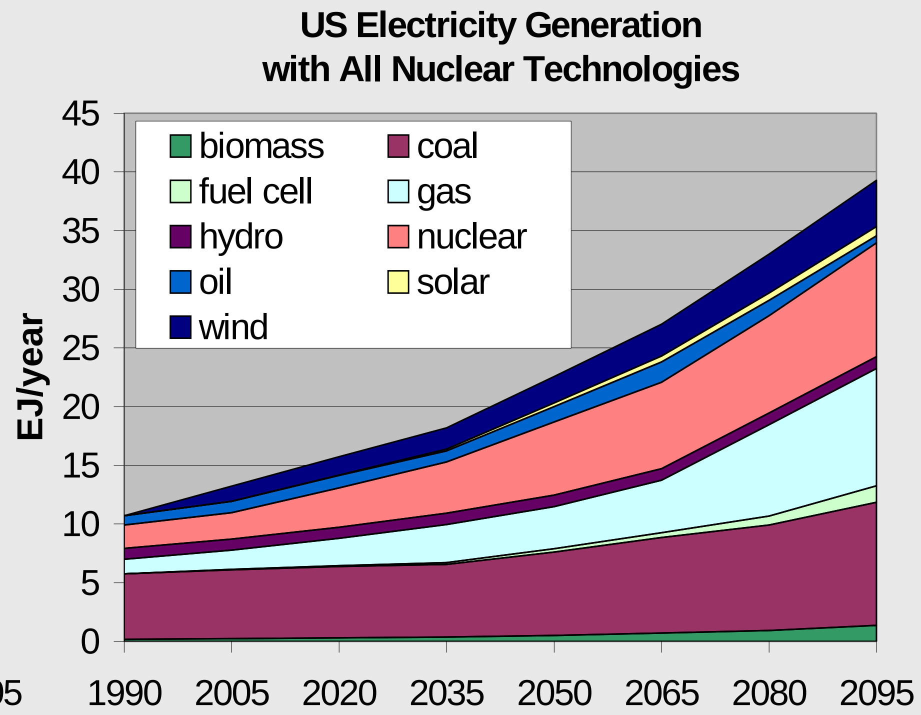
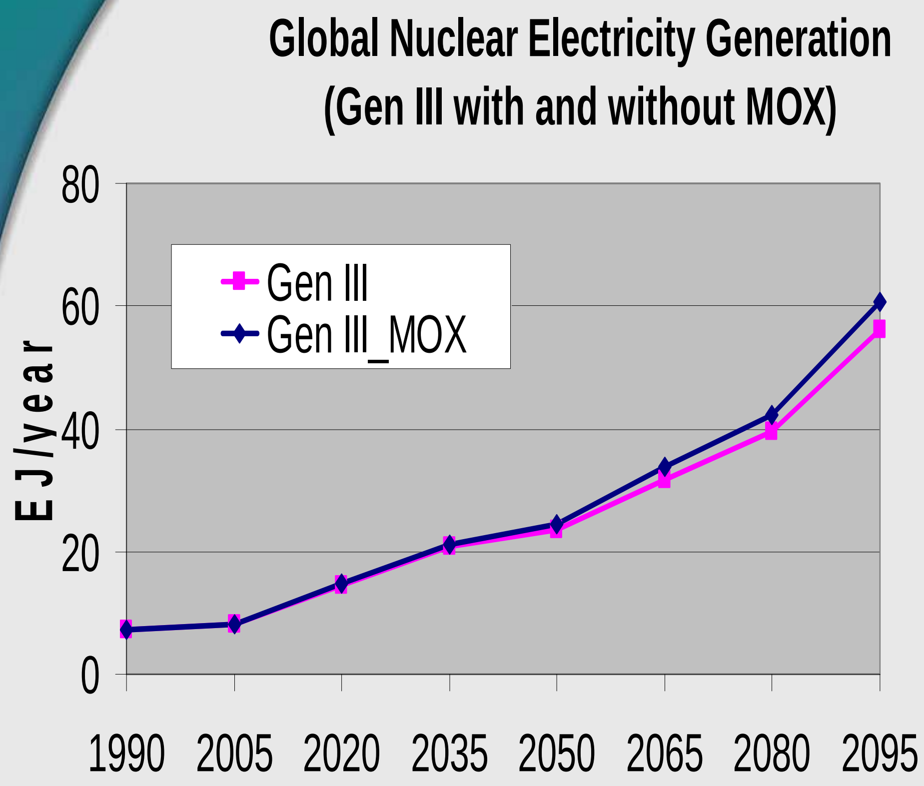
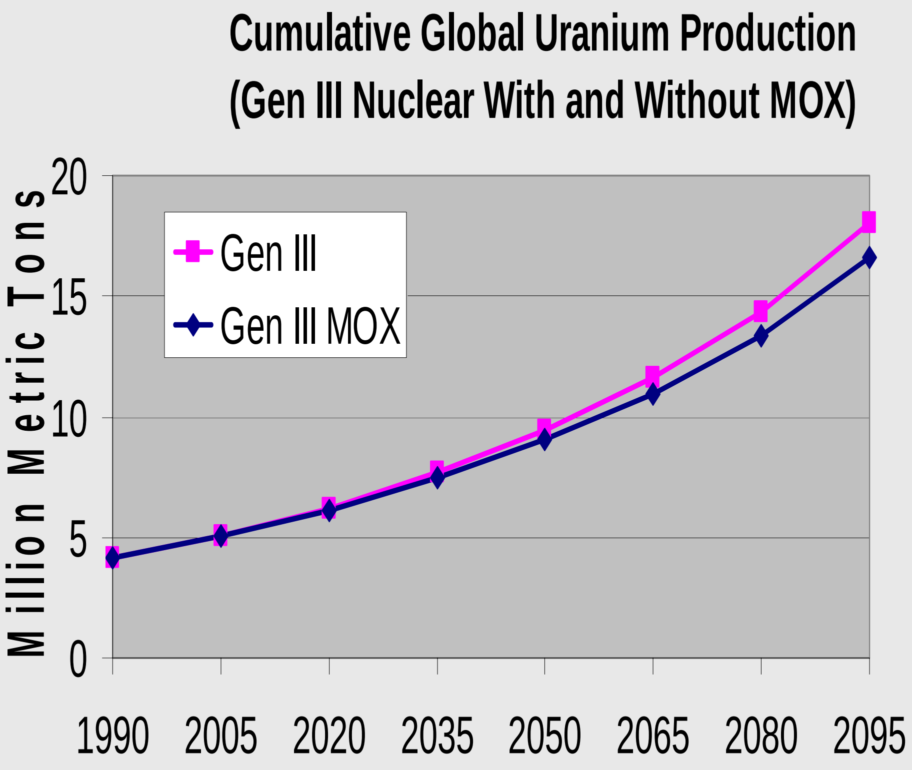
Reference Scenario: Electricity Generation





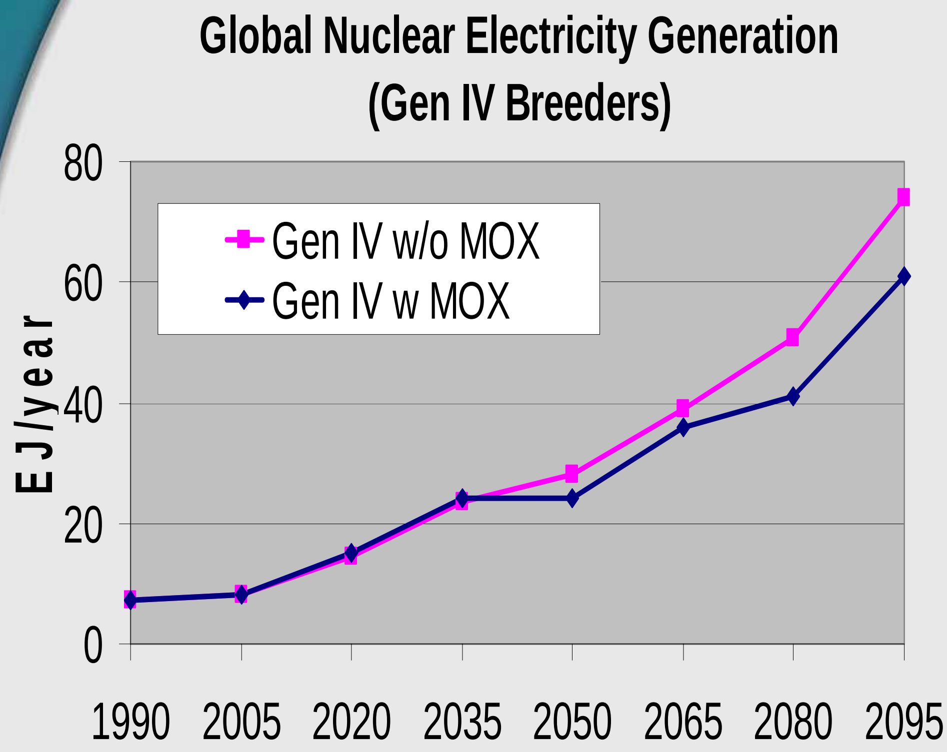
Reference Scenario: Gen III with and without MOX Fuel

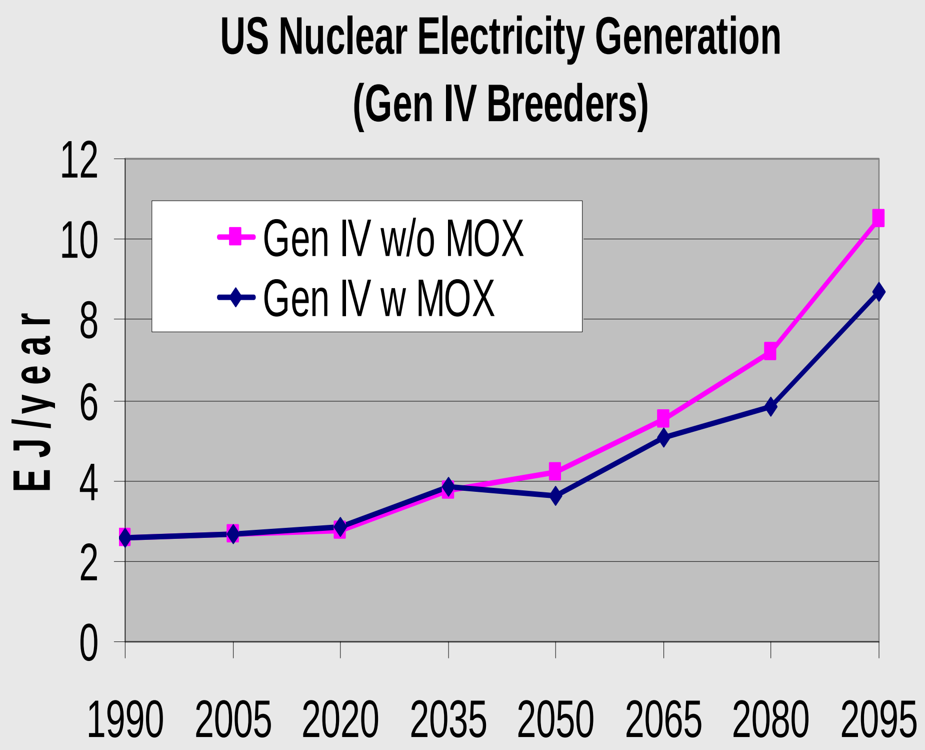




Reference Scenario: Gen IV Breeders with and without Gen III MOX

Competition for Plutonium





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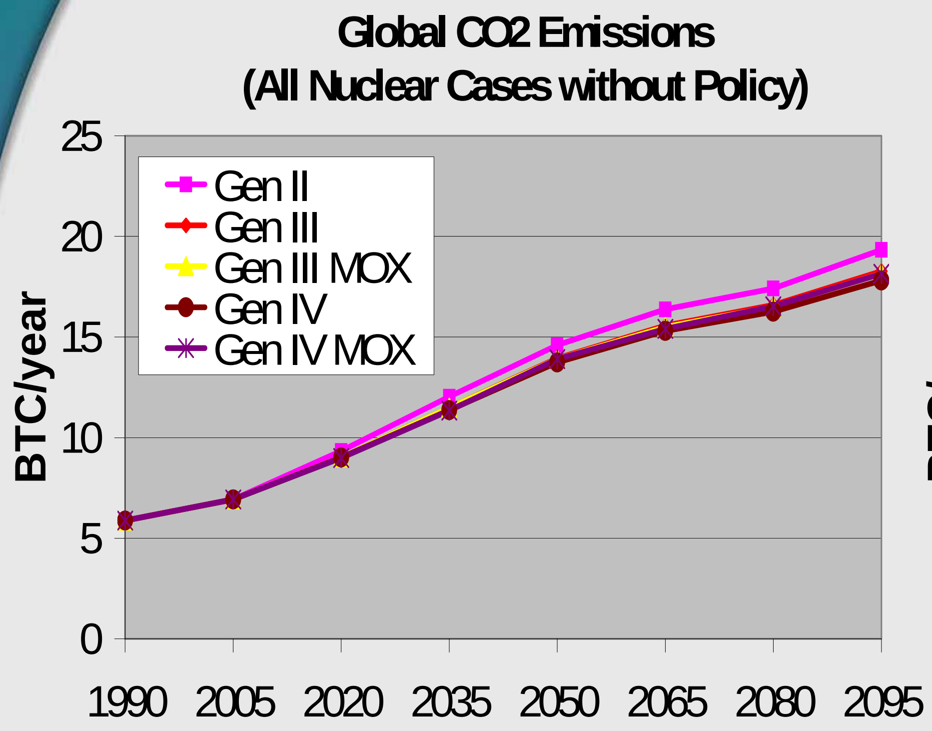
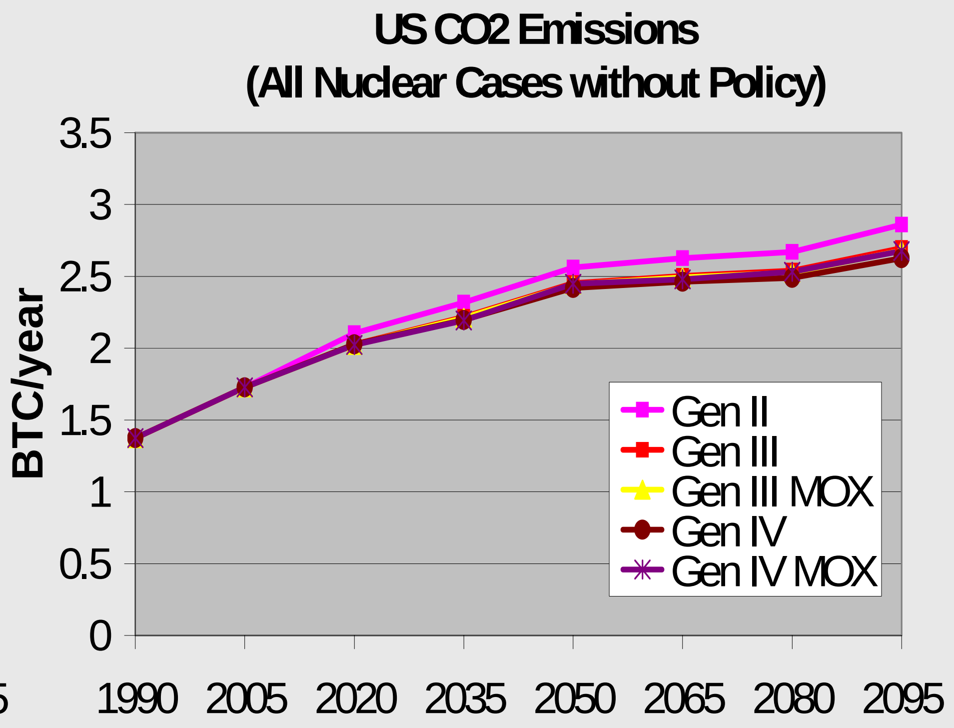
Reference Scenario: CO_2 Emissions
All Nuclear Technology Cases
(1.5 BTC/year Global Reduction by 2095)

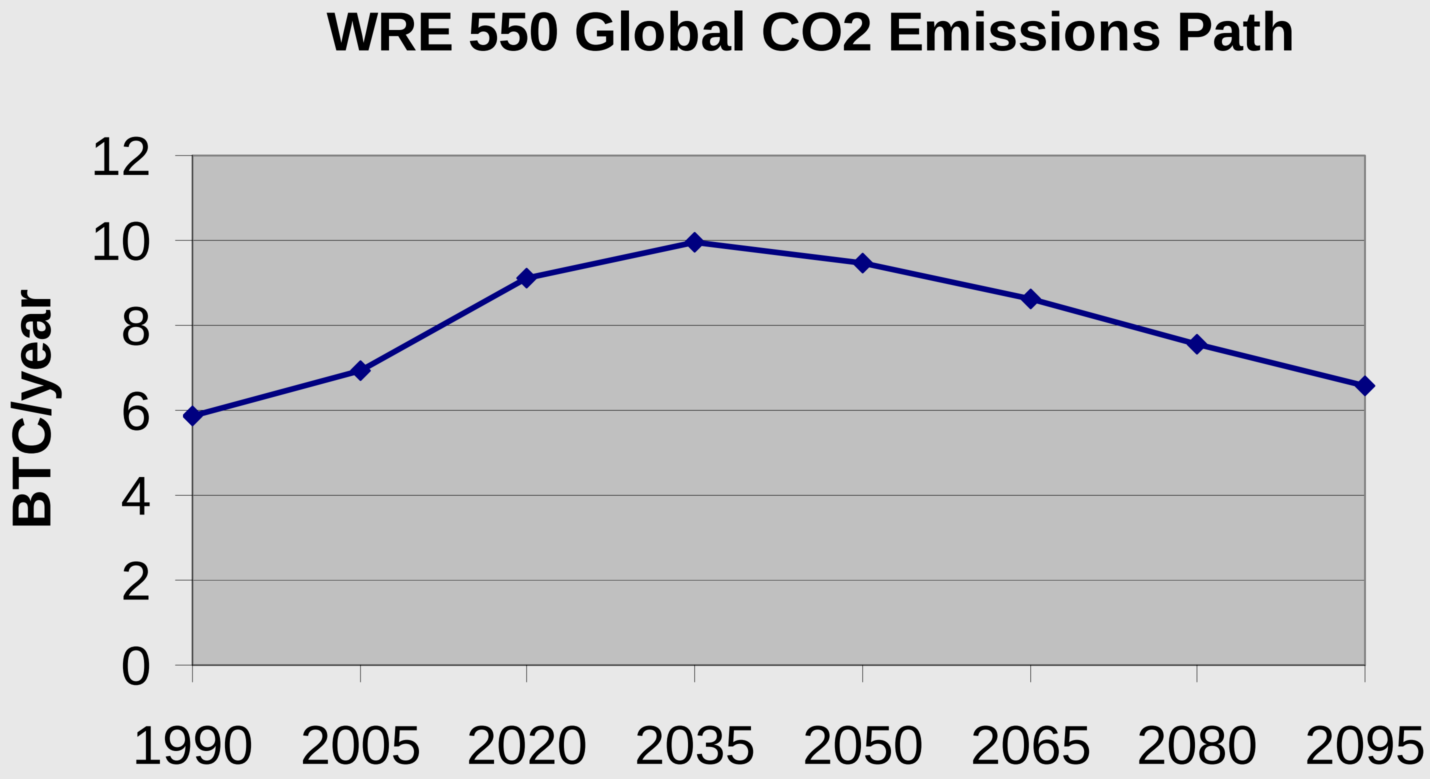




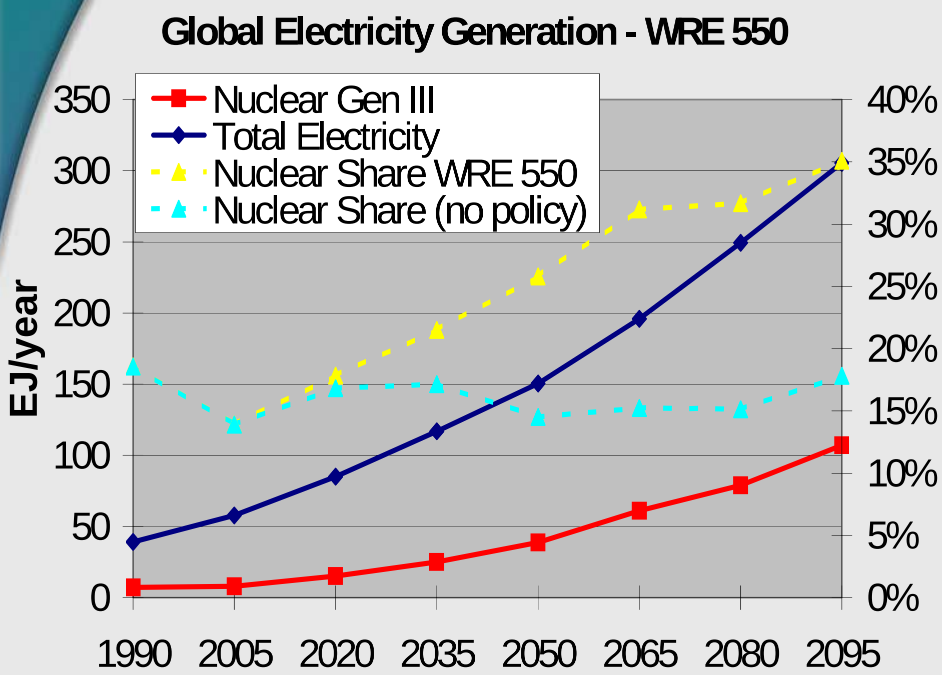
Carbon Policy Scenarios WRE 550 CO_2 Concentration Constraint

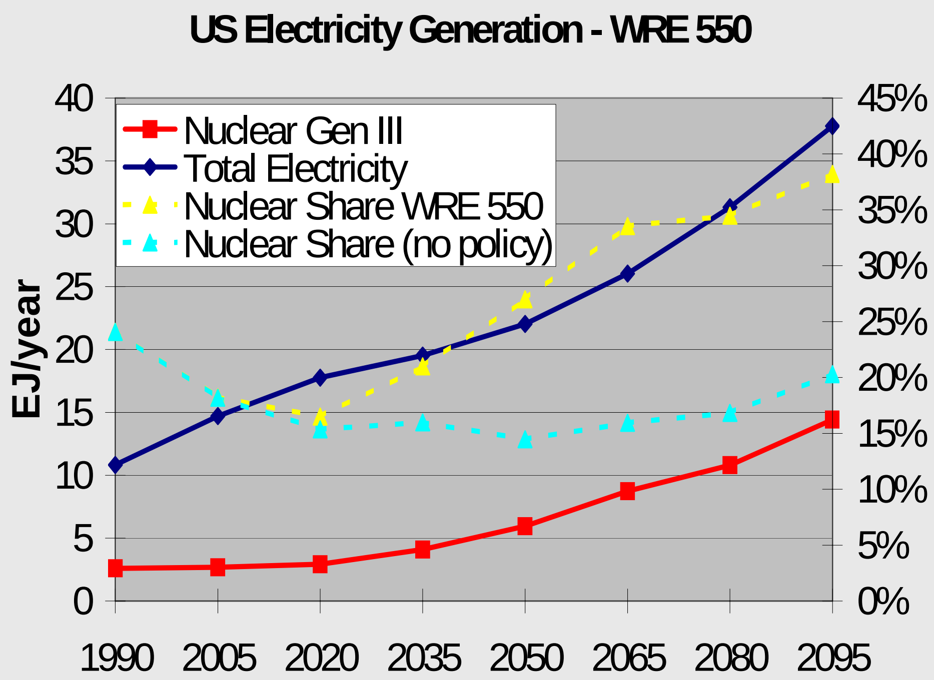
WRE 550 Scenario: Wigley, Richels and Edmonds

CO2 Emissions path for achieving a CO_2 concentration of 550 ppmv

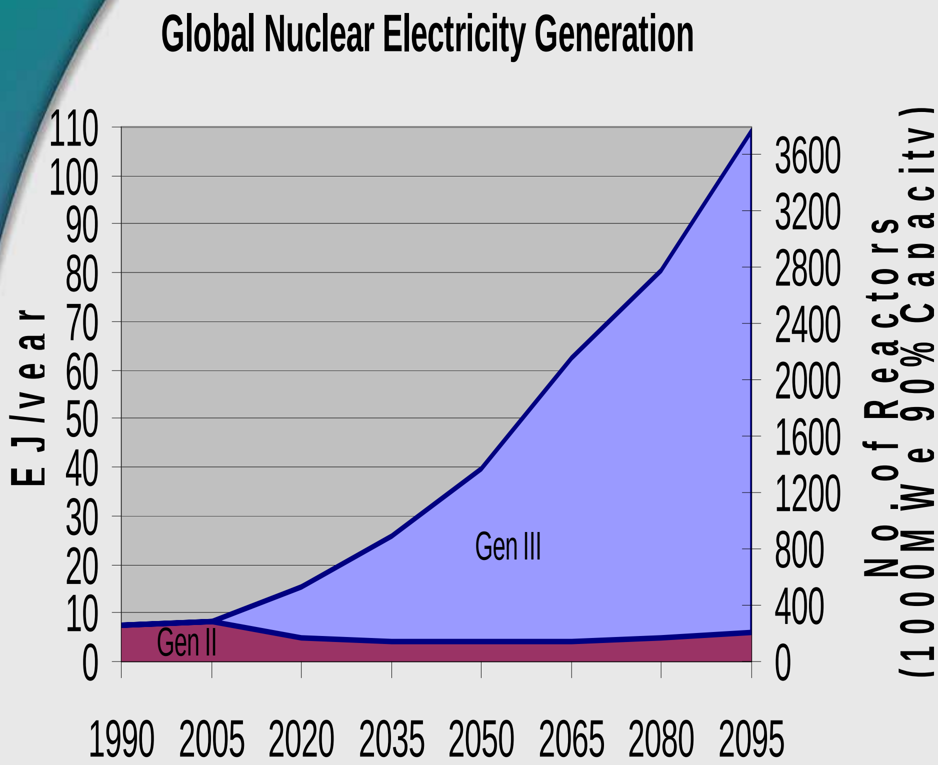


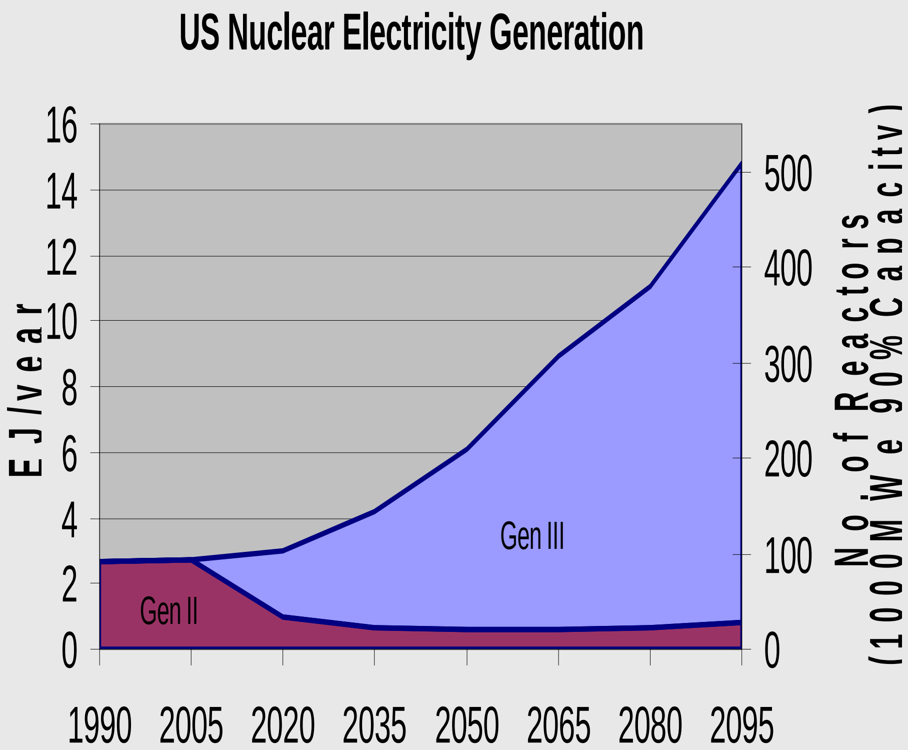
WRE 550 Scenario: Gen III Nuclear Power (no recycling)





WRE 550 Scenario: Nuclear Power with Gen III (no recycling)





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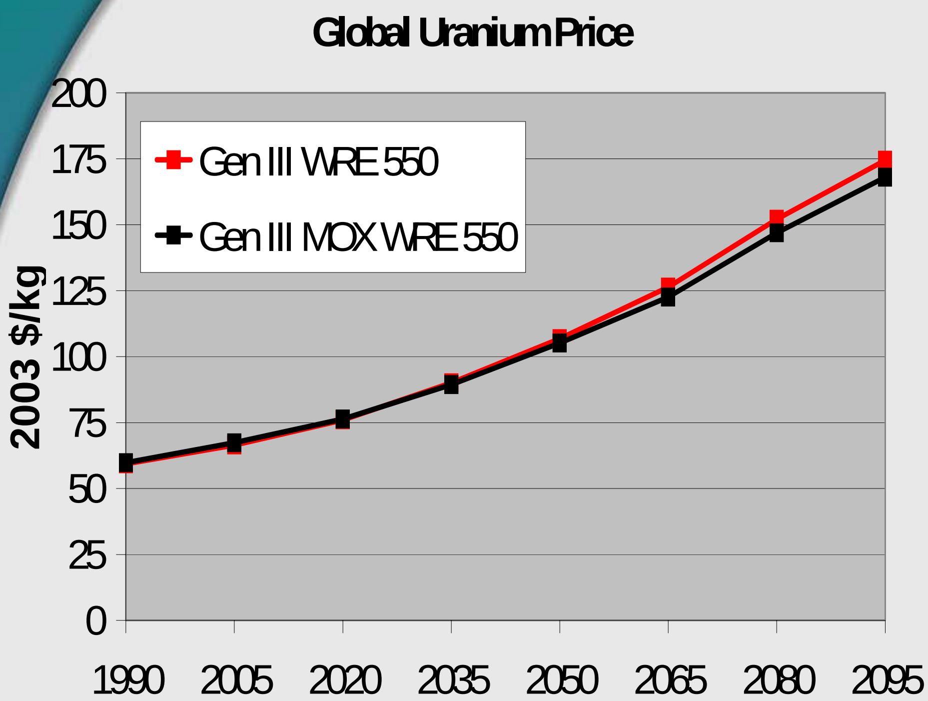
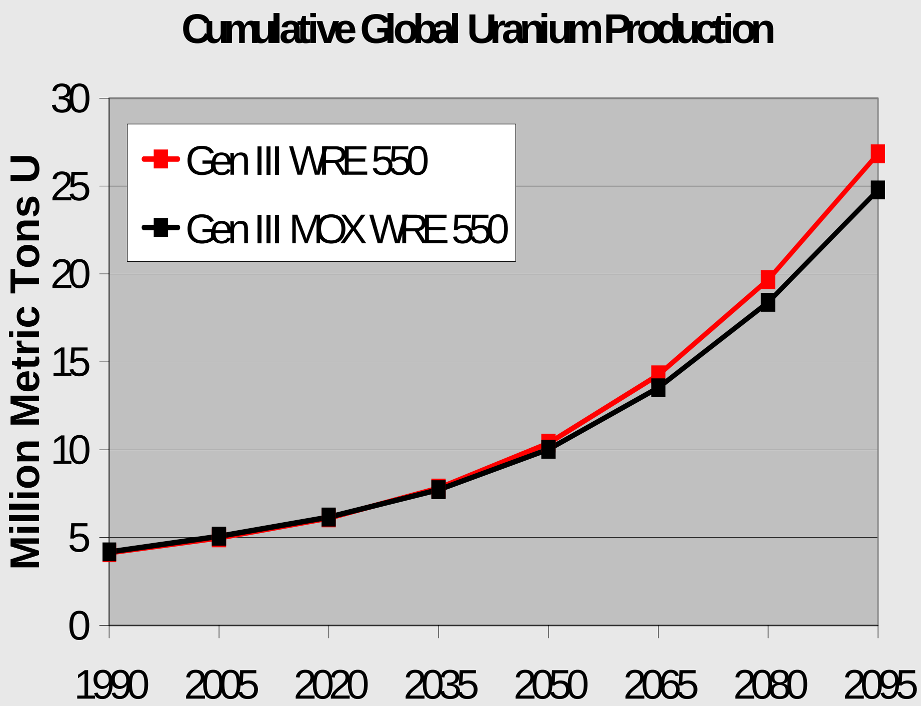
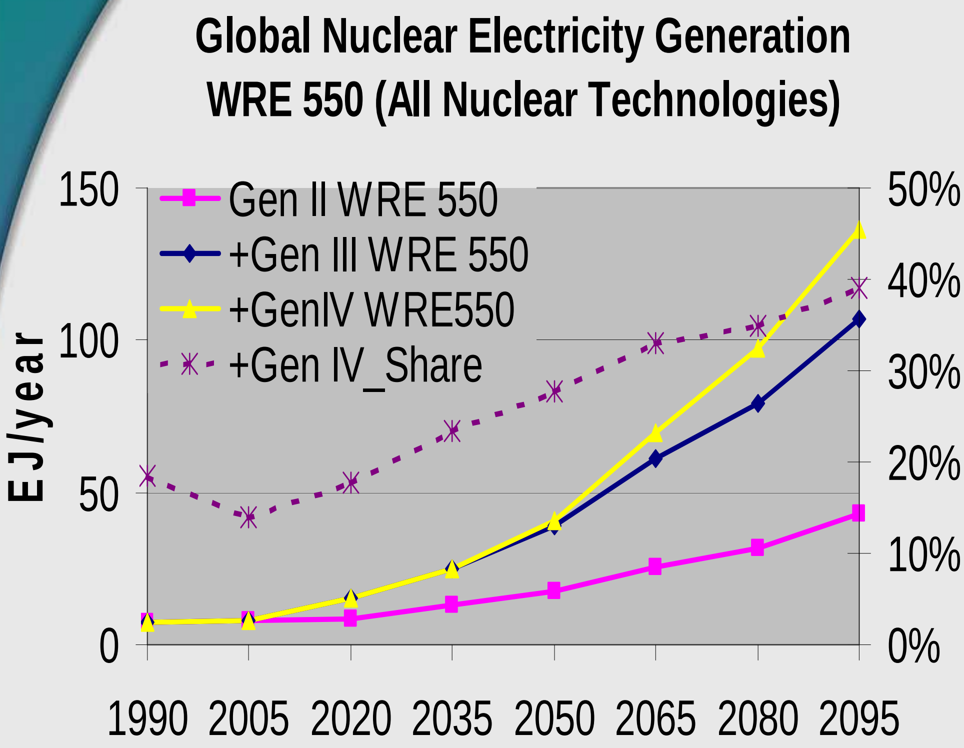
WRE 550 Scenario: Nuclear Power with Gen III (no recycling)

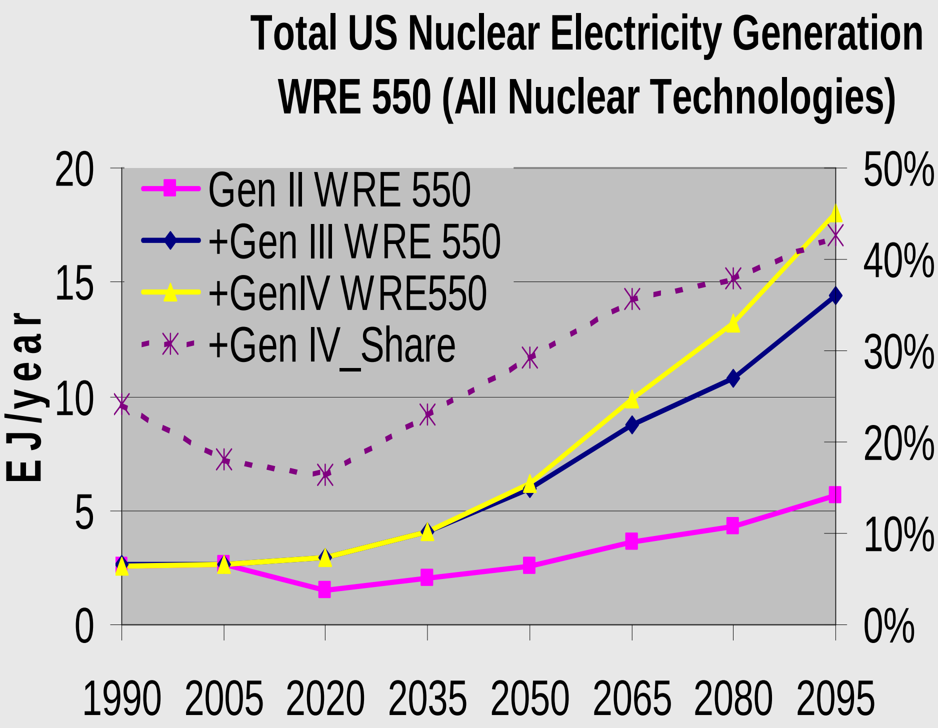




WRE 550 Scenario: All Nuclear Technologies

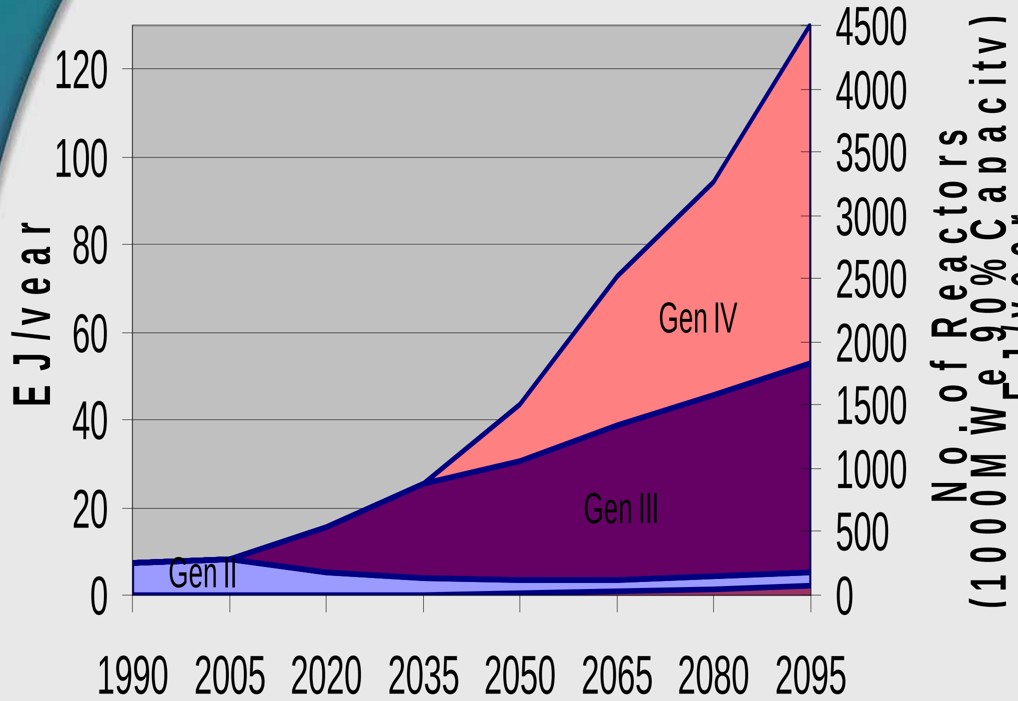
Gen IV Breeder Reactors



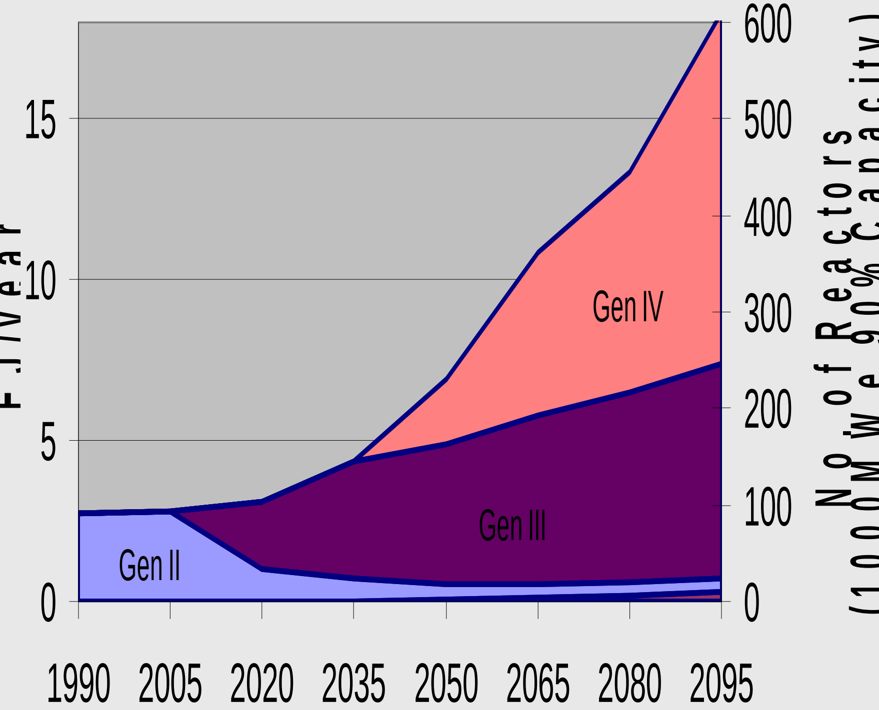


WRE 550 Scenario: All Nuclear Technologies

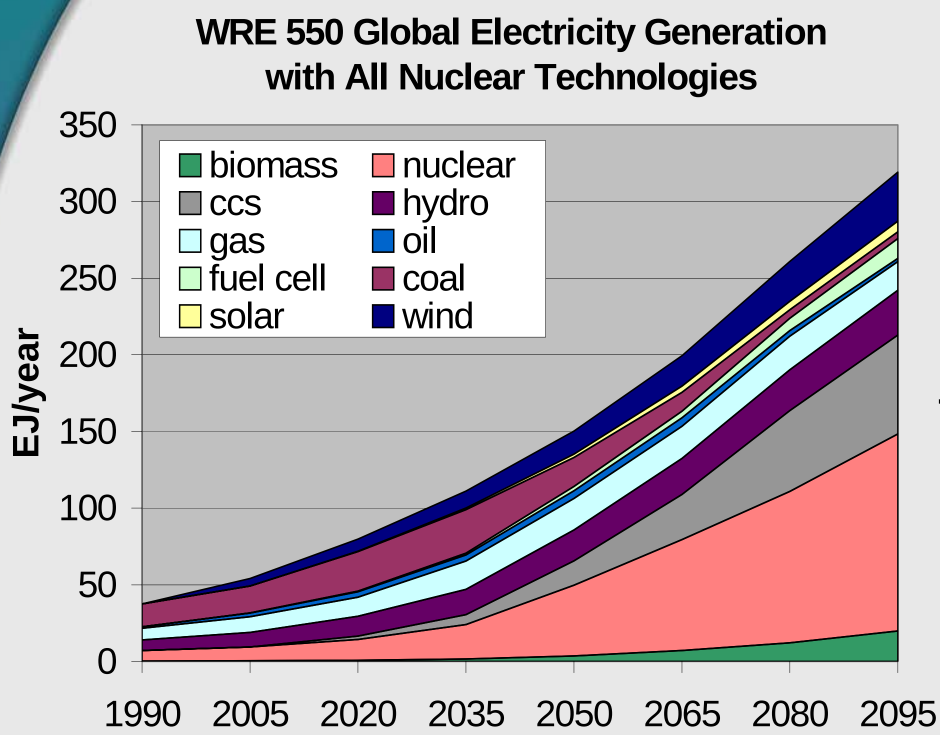
Global Nuclear Electricity Generation

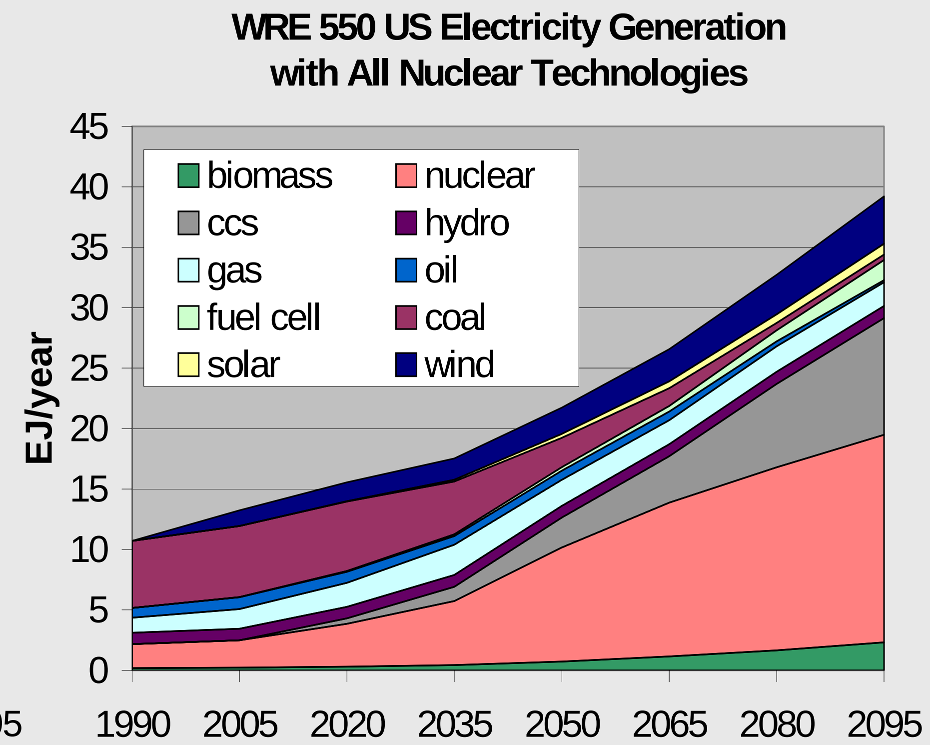


US Nuclear Electricity Generation

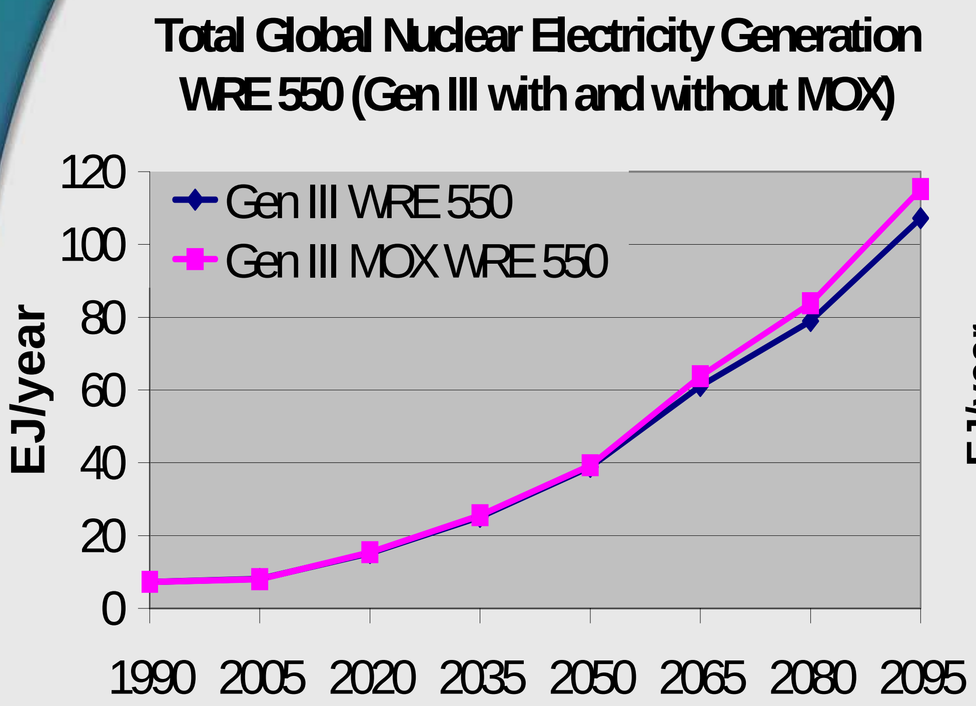


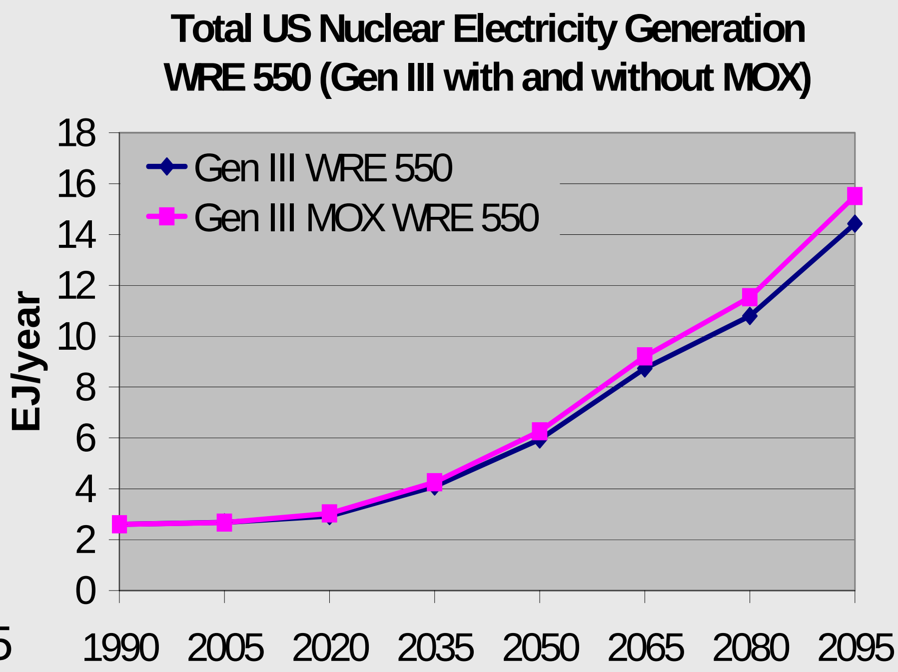
WRE 550 Scenario: Electricity Generation





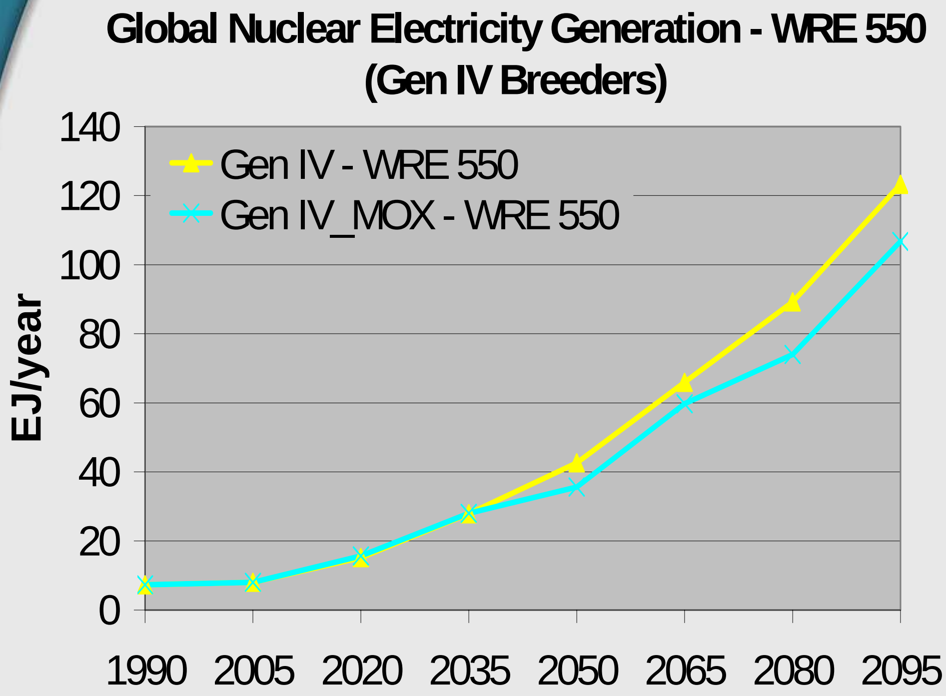
WRE 550 Scenario: Gen III with and without MOX Fuel

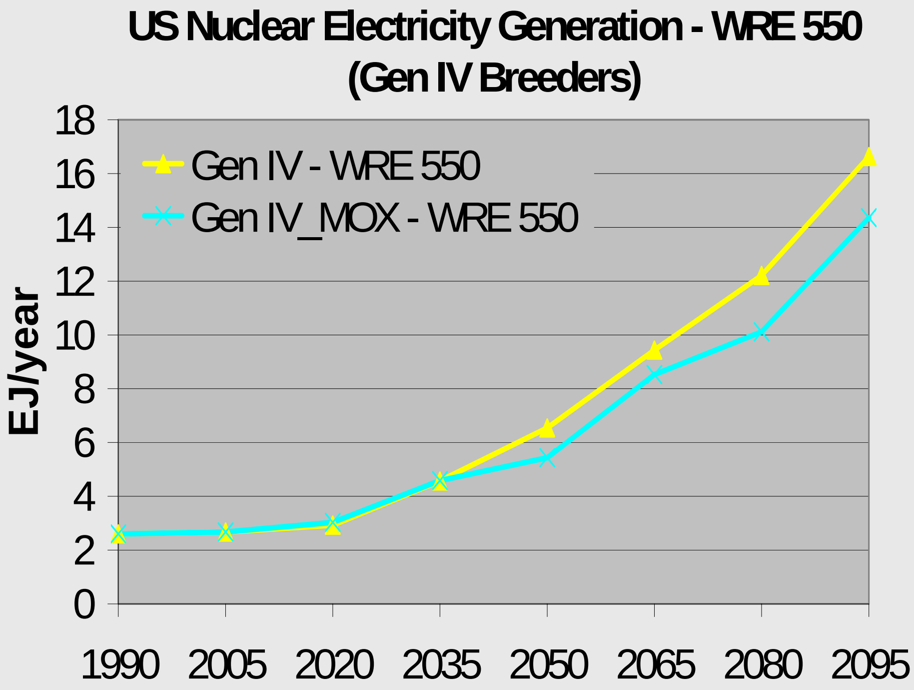




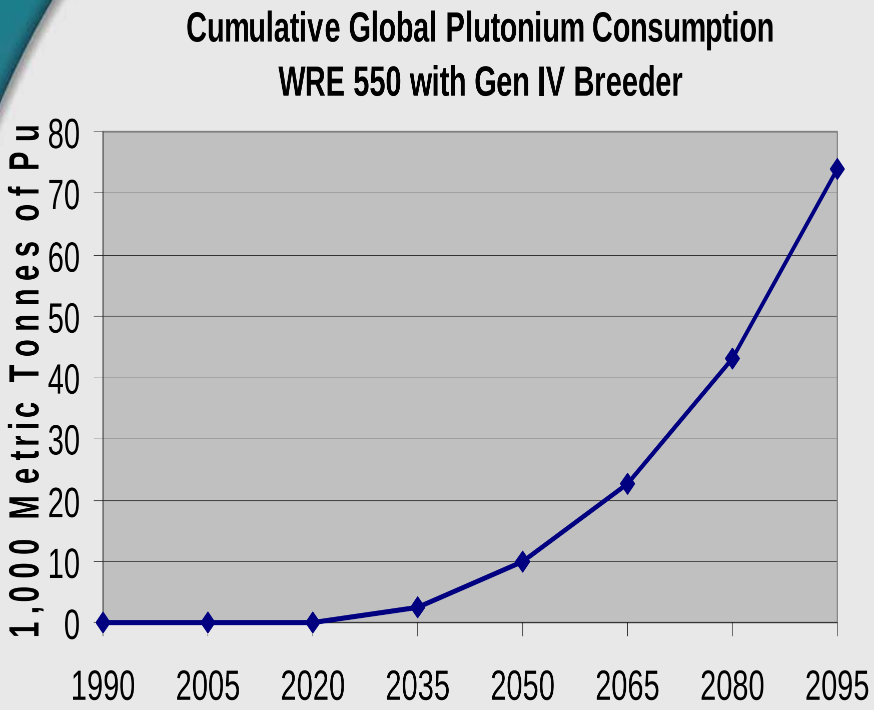
WRE 550 Scenario: Gen IV Breeders with and without Gen III MOX

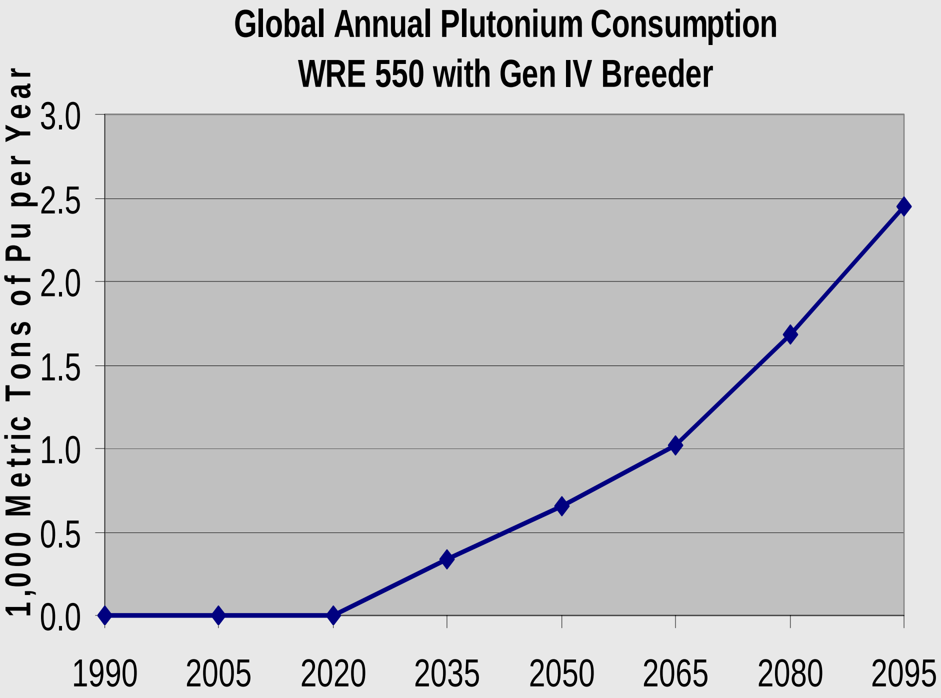
Competition for Plutonium





WRE 550 Scenario: Plutonium Consumption with Gen IV Breeders





Conclusions

- Without technology and economic improvements, nuclear power continues to lose market share (Gen II case).
- Advanced nuclear reactors, Gen III & IV's, with higher efficiencies and lower capital costs enable nuclear power to maintain current market share. Significant number of nuclear reactors (2000 to 2,600) by the end of the century.
- MOX does not significantly affect Gen III penetration, but its use could potentially hinder Gen IV Breeder expansion.
- In the absence of a carbon policy, nuclear power alone does not solve the climate change problem.

Conclusions

- Under carbon policies, nuclear energy with Gen IV reactors is potentially the largest source of electricity in the latter half of the century (3600 – 4500 reactors).
- Gen III reactors alone provide a robust and significant carbon-free option under carbon policies, and the long-term success of nuclear energy hinges on the success of Gen III reactors.
- Emphasis on lowering the capital cost of advanced nuclear technologies is the key to nuclear competitiveness in the near future.

Future Studies

- Developing the details--sensitivity cases on advanced nuclear technologies
  - Power plant efficiencies (burn-up and heat-rate) and capital costs.
  - Fuel fabrication costs and efficiencies in mining and enrichment.
- Global or limited availability of advanced nuclear technologies
- Regional vs. global market for uranium and plutonium, and sensitivity cases on uranium supply and price.
- H_2 production from nuclear power.