Overall Effect of Space Resources on Earth-Moon System

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Lecture 37

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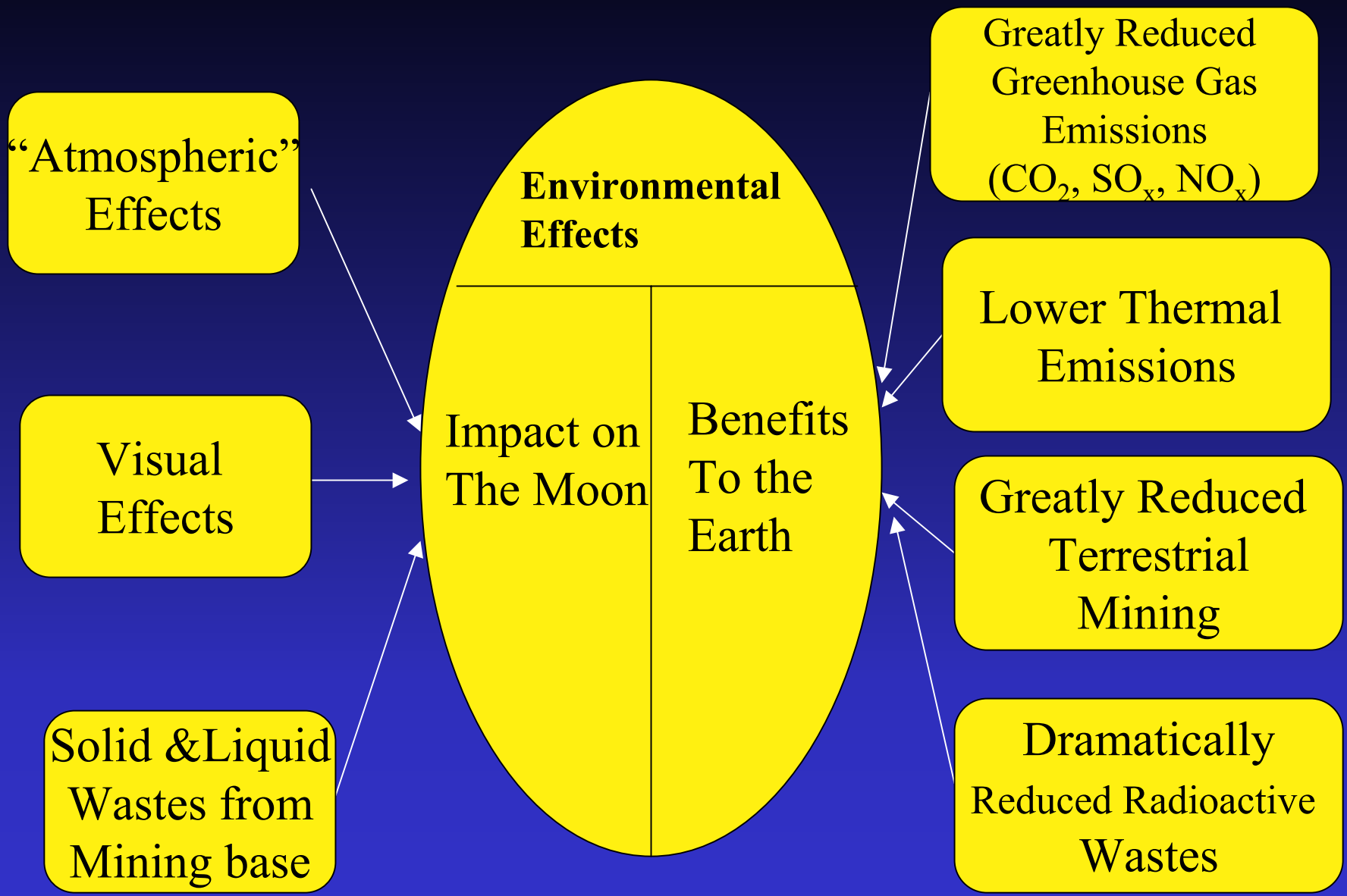
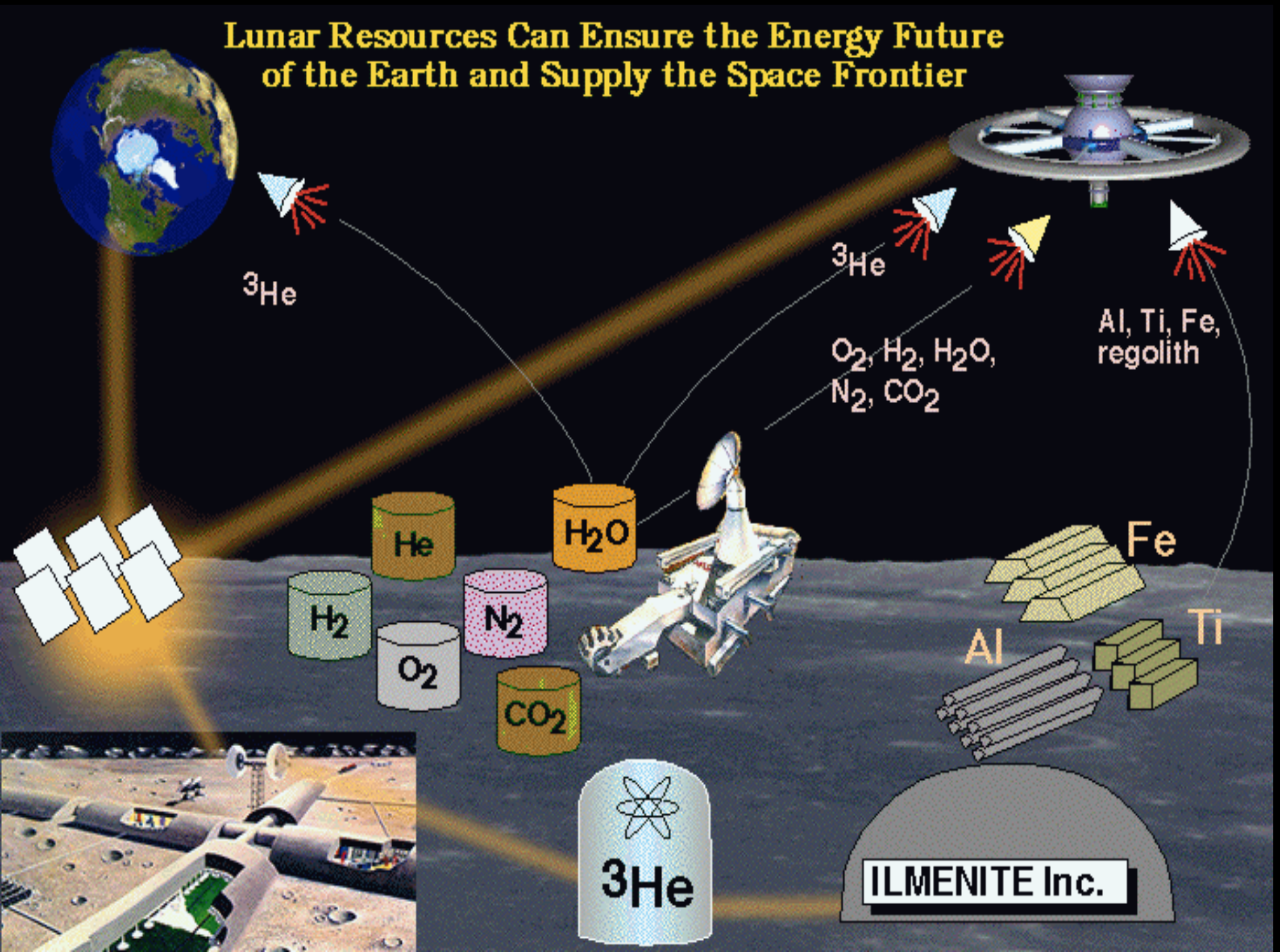
"Net" Environmental Considerations for Energy from Space



What Resources from the Moon Can Have a Major Impact on Future Generations?

	Energy	Volatiles, Metals, and Minerals
On Earth	• ^3He • Microwaves from Solar Power	Probably None
In Space	• ^3He • Microwaves from Solar Power • H_2-O_2 fuel cells	• Volatiles (H_2, N_2, O_2, CO_2, etc.) • Al. Fe, Ti, etc. • Regolith
On the Moon	• ^3He • Solar Power • H_2-O_2 fuel cells	• Volatiles (H_2, N_2, O_2, CO_2, etc.) • Al. Fe, Ti, etc. • Regolith


Lunar Resources Can Ensure the Energy Future
of the Earth and Supply the Space Frontier
3He
3He
O2, H2, H2O,
N2, CO2
Al, Ti, Fe,
regolith
He
H2O
H2
N2
O2
CO2
Fe
Al
Ti
3He
ILMENITE Inc.

Possible Effects on the Lunar "Atmosphere"

- Vondrak has shown that the volatile release rate would have to be >0.1 kg/s to equal the solar wind.

- Assuming:

  1). The solar wind flux can be exceeded by a factor of 10 before there is any detectable change in the lunar "atmosphere".

  2). Only 1% of mined volatiles escape during mining

- Implications:
  - No harmful effects will occur if < 15 billion tonnes of regolith mined/y (2065)

- Note: Each Apollo landing released≈ 10 tonnes of volatiles (≈ entire mass of the lunar atmosphere) w/o harmful effects

Possible Effects on the Albedo of the Lunar Surface

- All craters <20 m in diameter will be removed by mining. All craters >20m (≈4% of surface area in Mare) will remain and contain the "record" of smaller impact craters
  - None will be visible from Earth even with the most powerful telescopes
- Normal albedo of Mare materials is 7-10%
  - Apollo photographs revealed darkening (lower albedo) where astronauts have disturbed the regolith
  - Observations a few 100 meters from LM revealed a slight lightening (higher albedo) due to engine exhaust
  - "Down sun" photos several 100 meters from disturbed Mare areas show no obvious change in surface albedo

Solid Waste from Human and Mining Activities

- It is assumed that most items on the Moon will be recycled
- Those items that cannot be recycled can be buried in a crater for future retrieval if desired
- The lack of water means that discarded equipment will not deteriorate and there is no mechanism for the migration of wastes

Overview of Energy Sources From Space

Energy Sources Now Used on Earth	Could This Be economically Imported from Space?	What Energy Source/Fuel Might We Want to Use on Earth?	Could This Be economically Imported from Space?
Oil	No	Fusion	
Coal	No	deuterium	No
Natural Gas	No	Li (for tritium)	No
Hydro	No	^{3}He	Yes
Fission	No	^{11}B	No
Geothermal	No	Microwaves	
Biomass	No	Solar	Yes
Wind	No	Fission	Possible
Solar PV	See future		

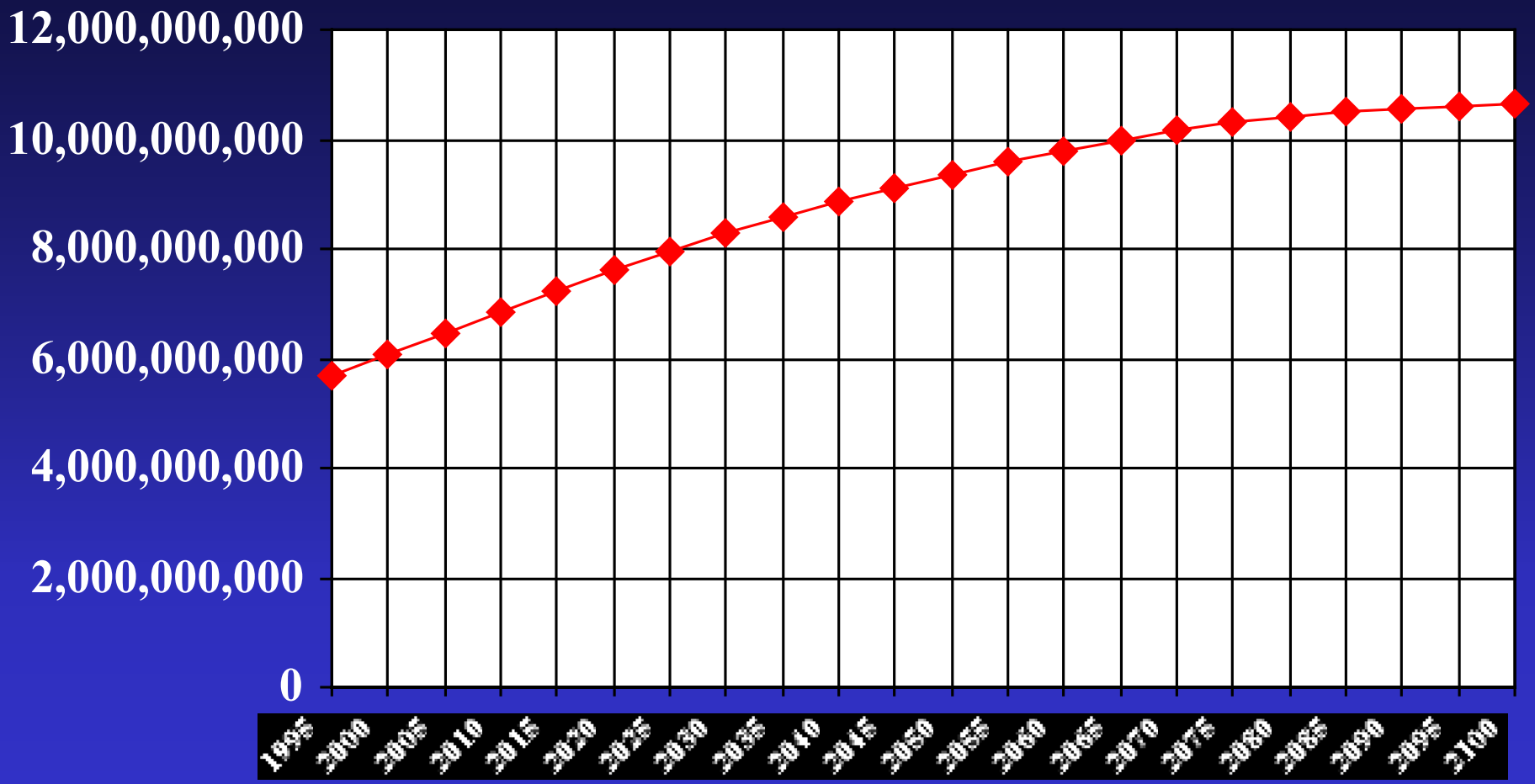
How Much Energy Will be Needed on Earth in the Future?

- Nobody knows exactly!
  - Make a conservative guess
- Use the population times energy/capita approach
- World Population
  - Use US census Bureau predictions to 2050
    - Growth rates from from 1.4% now to 0.5% in 2050
  - Assume growth rates drop linearly from 2050 to 2100
    - No growth after 2100
- World Average Energy Use/Capita
  - 1.) use 11 boe/capita-y in 1995
  - 2.) use 15 boe/capita-y in 2050
  - 3.) use 11 boe/capita-y in 2100

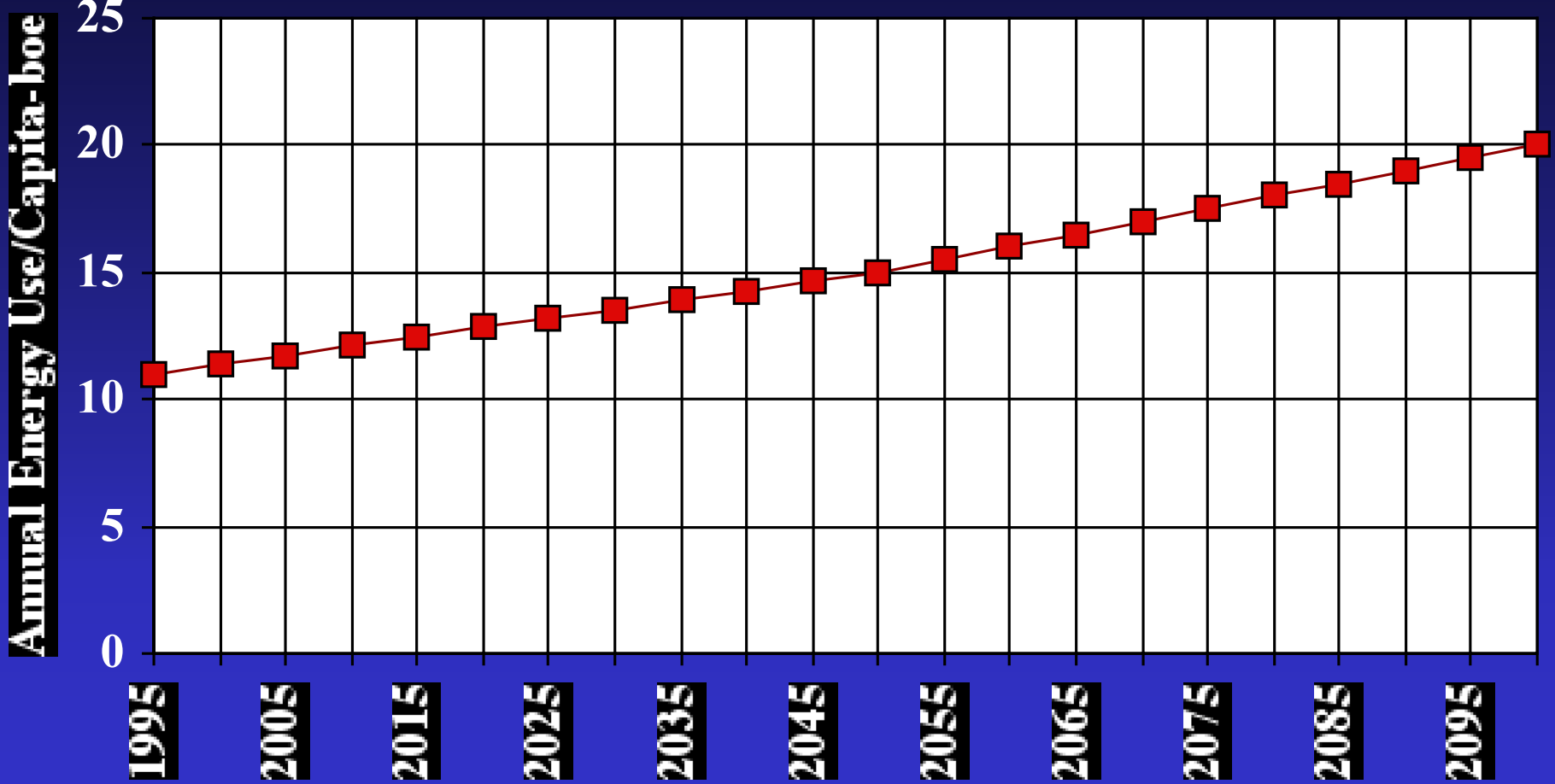
The World Energy Demand is the Product of Two Simple Numbers

X

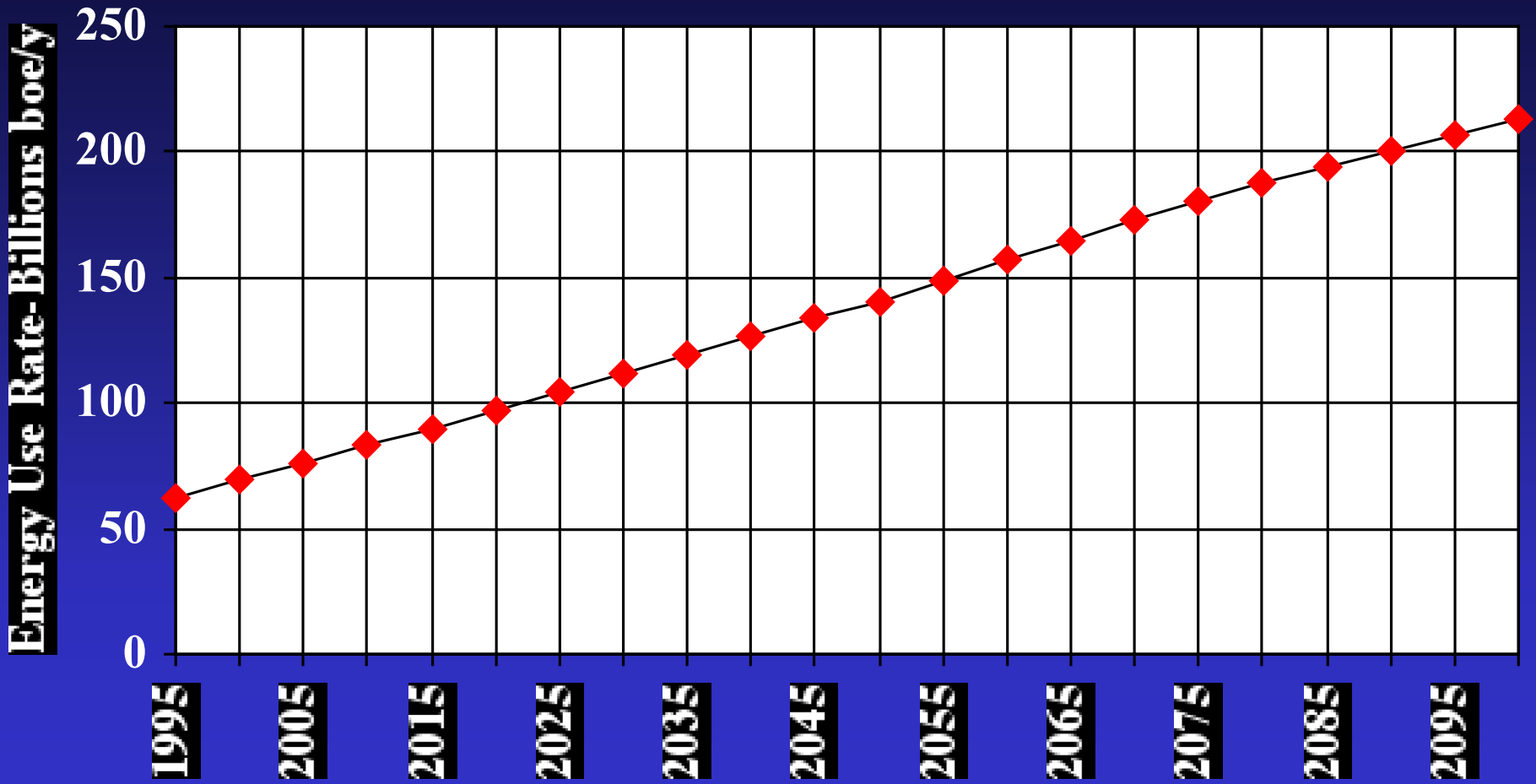
The World Population is Assumed to Asymptotically Approach 10.6 Billion People by 2010



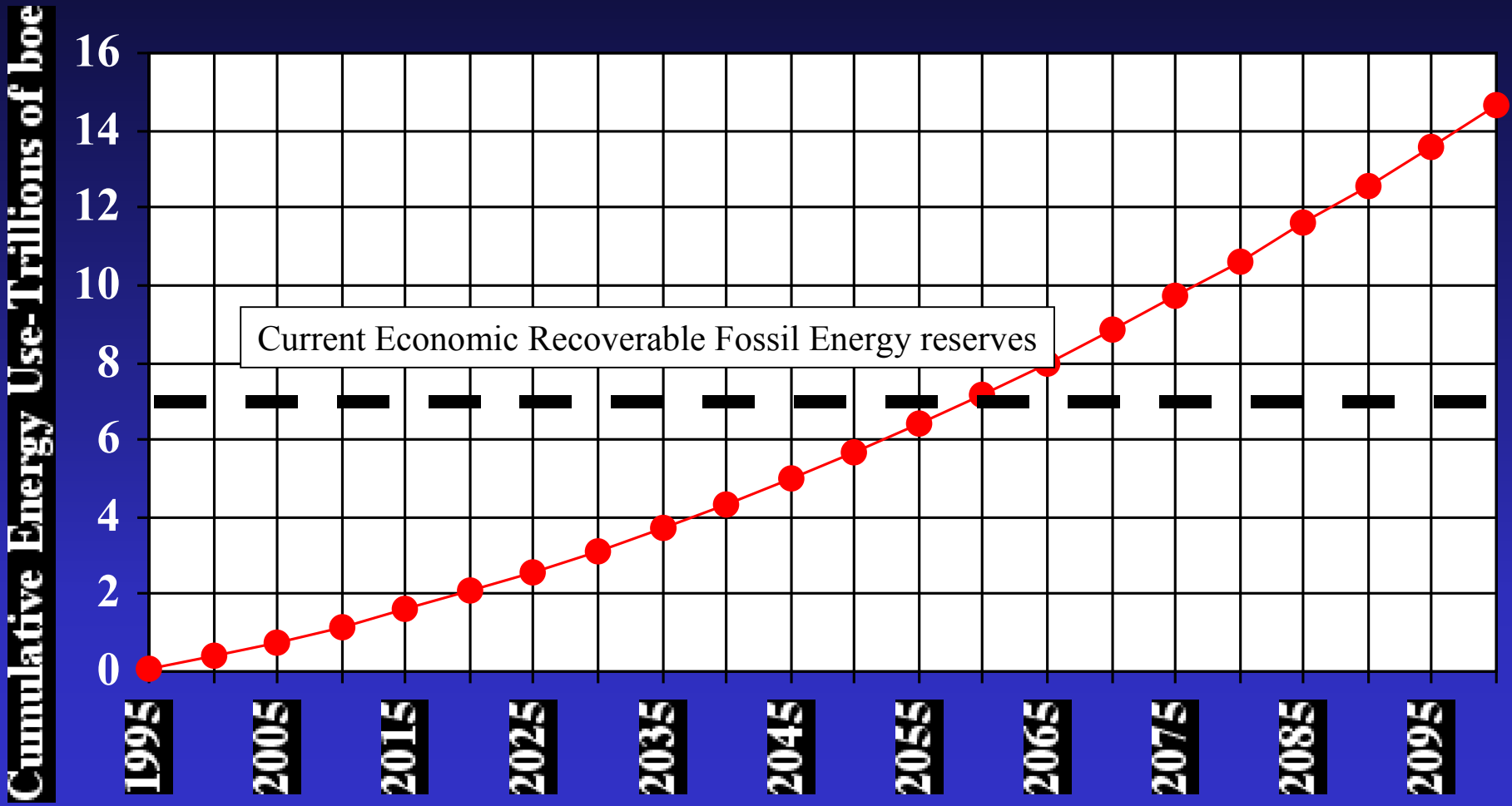
The Average Annual World Energy Use Per Capita is Likely to Double Over the Next Century



The Annual World Energy Use Rate is Likely to Increase by a Factor of 3-4 in the Next Century



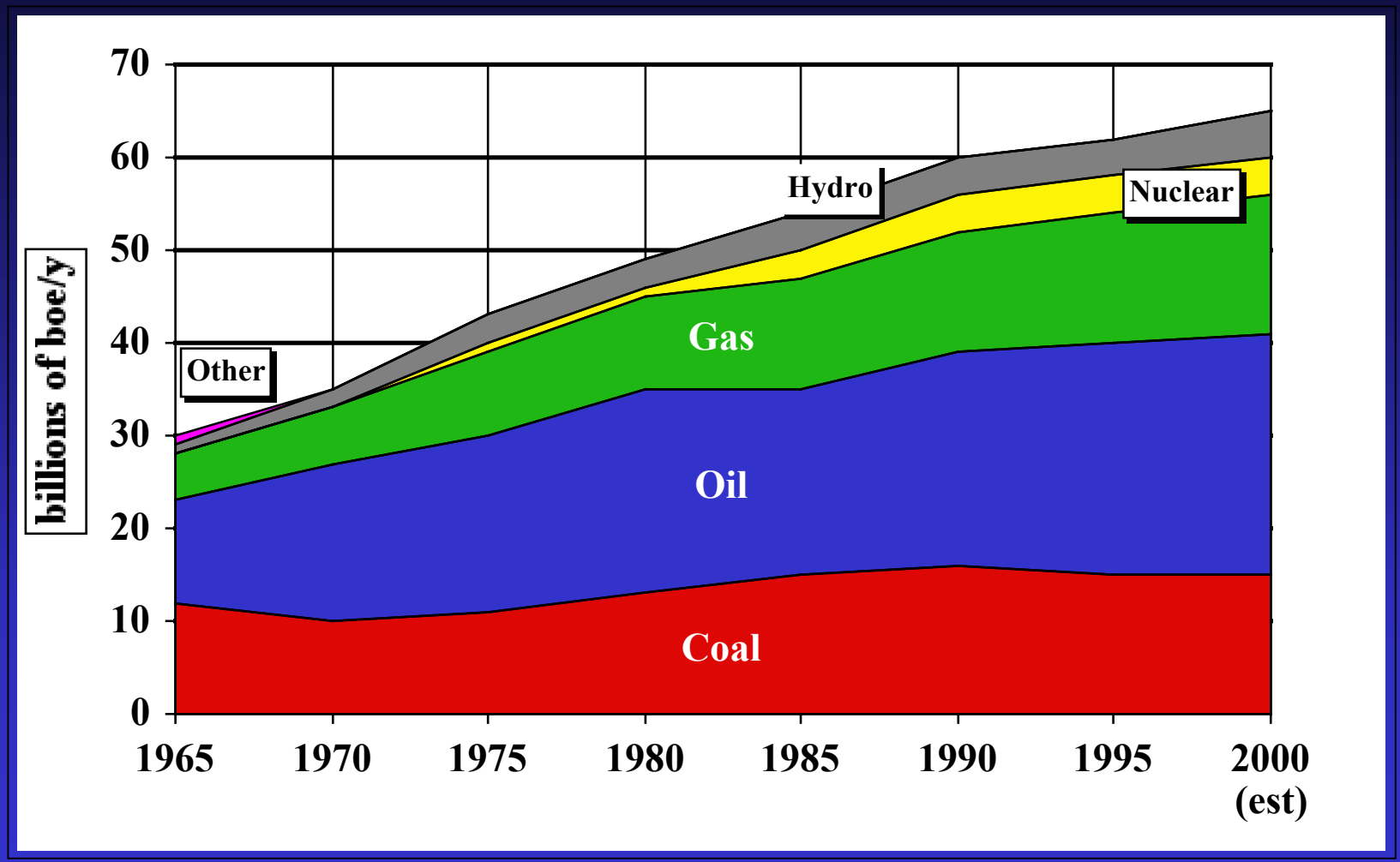
The Cumulative World Energy Use Between Now and 2100 is ≈ Twice the Known World's Economic Recoverable Fossil Fuel Reserves



How Are the Future World Energy Requirements Going to Be Met?

- Scenario 1
  - Stay with the present mix of world energy sources until they run out
    - Define gap between demand and supply
- Scenario 2
  - Introduce new energy source in year 20?? with realistic market penetration rate
- Scenario 3
  - Introduce new energy source at an aggressive rate to meet demand as fossil fuels run out

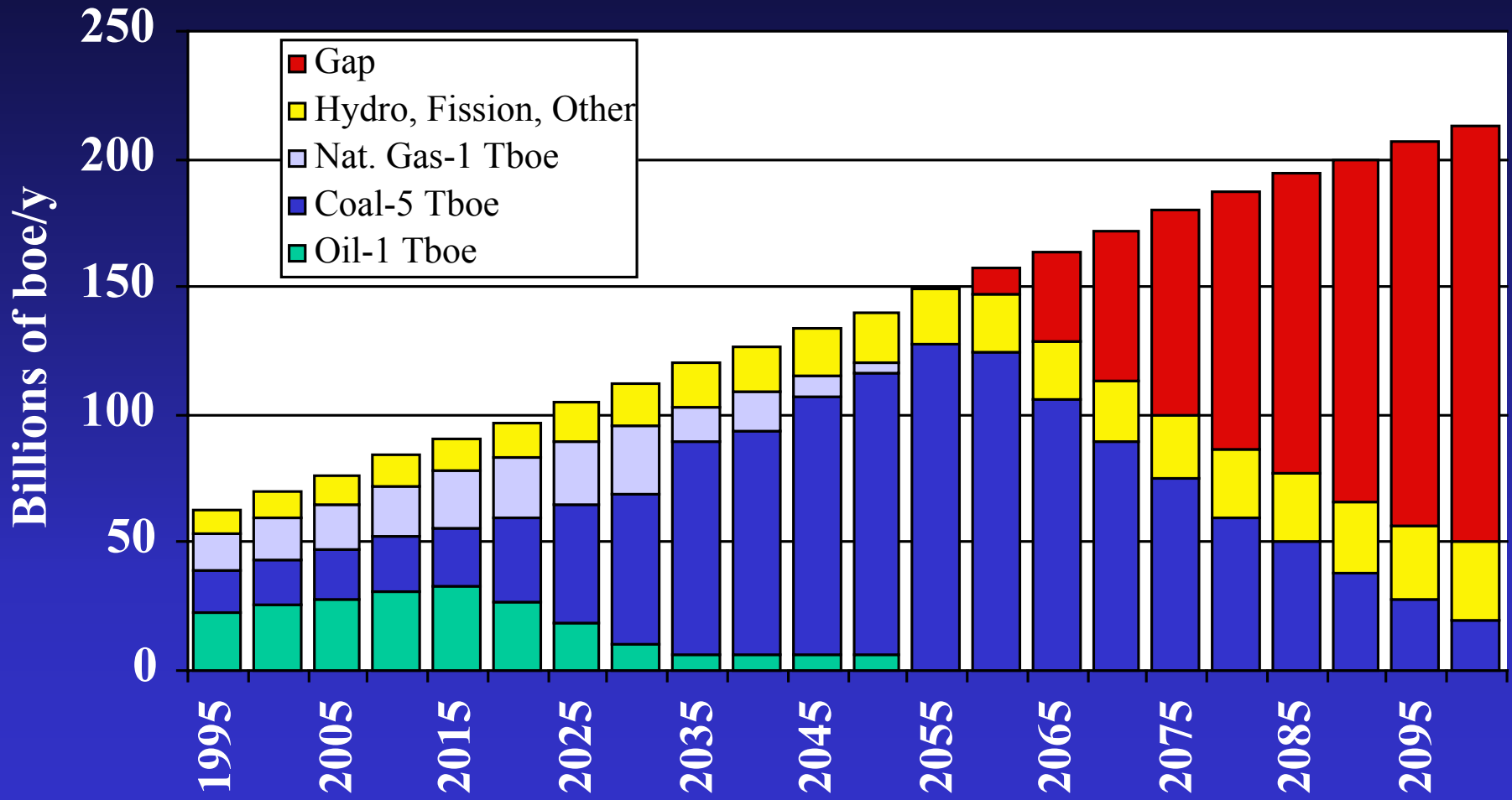
Fossil Fuels Still Account for Over 85% of the Primary Energy Consumed in the World



What Are the Major Assumptions in Scenario 1?

- In 25 years, coal will be used to substitute for liquid and gaseous fuels
- Electricity will account for 40% of the world's energy demand, 50% by 2025, 60% by 2050, 70% by 2075, and 80% by 2100
- Hydro, fission, and other sources of energy will continue to capture ≈ 14% of the energy market
- Society will allow the burning of all the economically recoverable fossil fuels in the 21st century

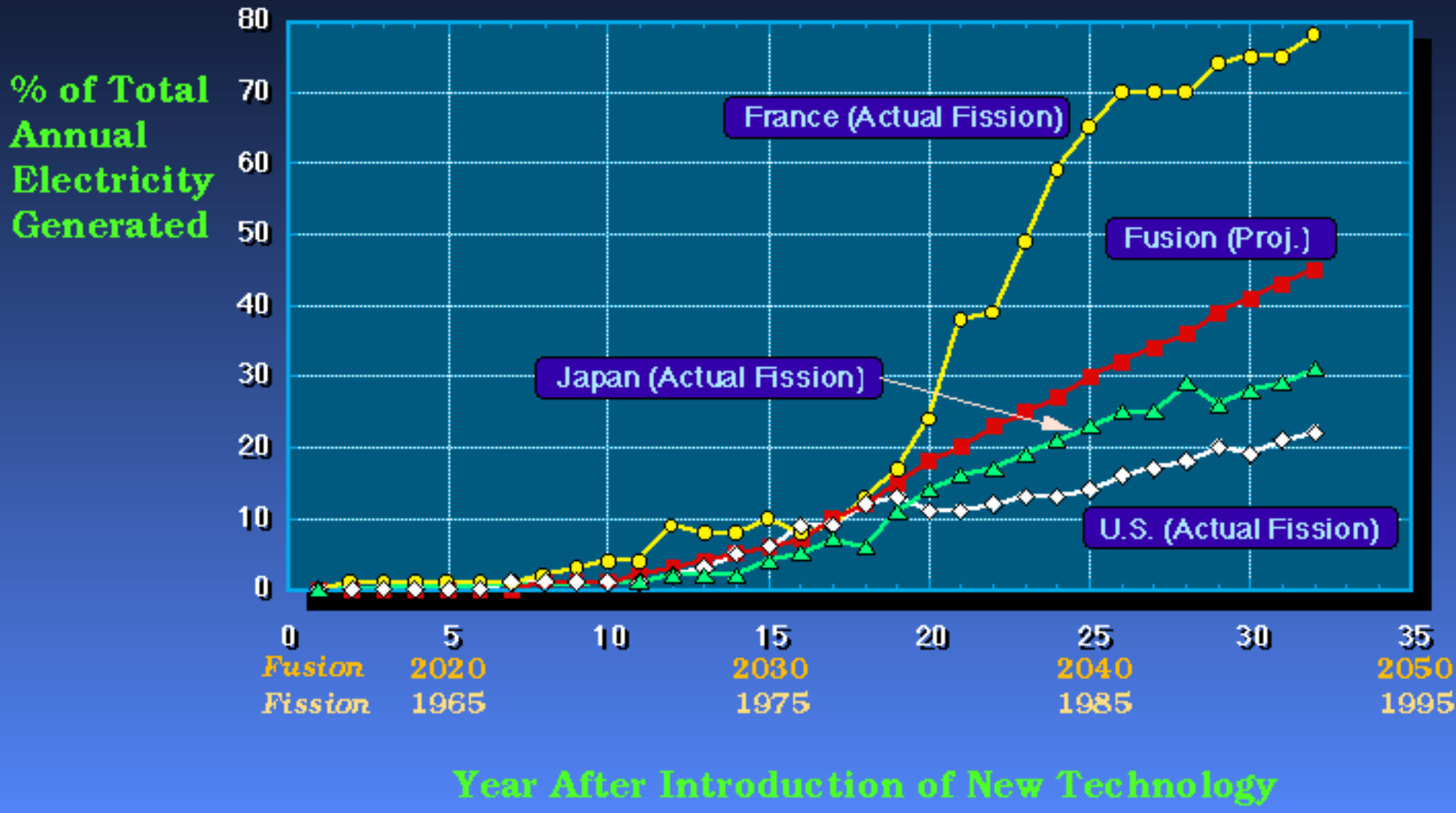
The Virtual Exhaustion of Fossil Fuels in the 21st Century Will Require a New Energy Source



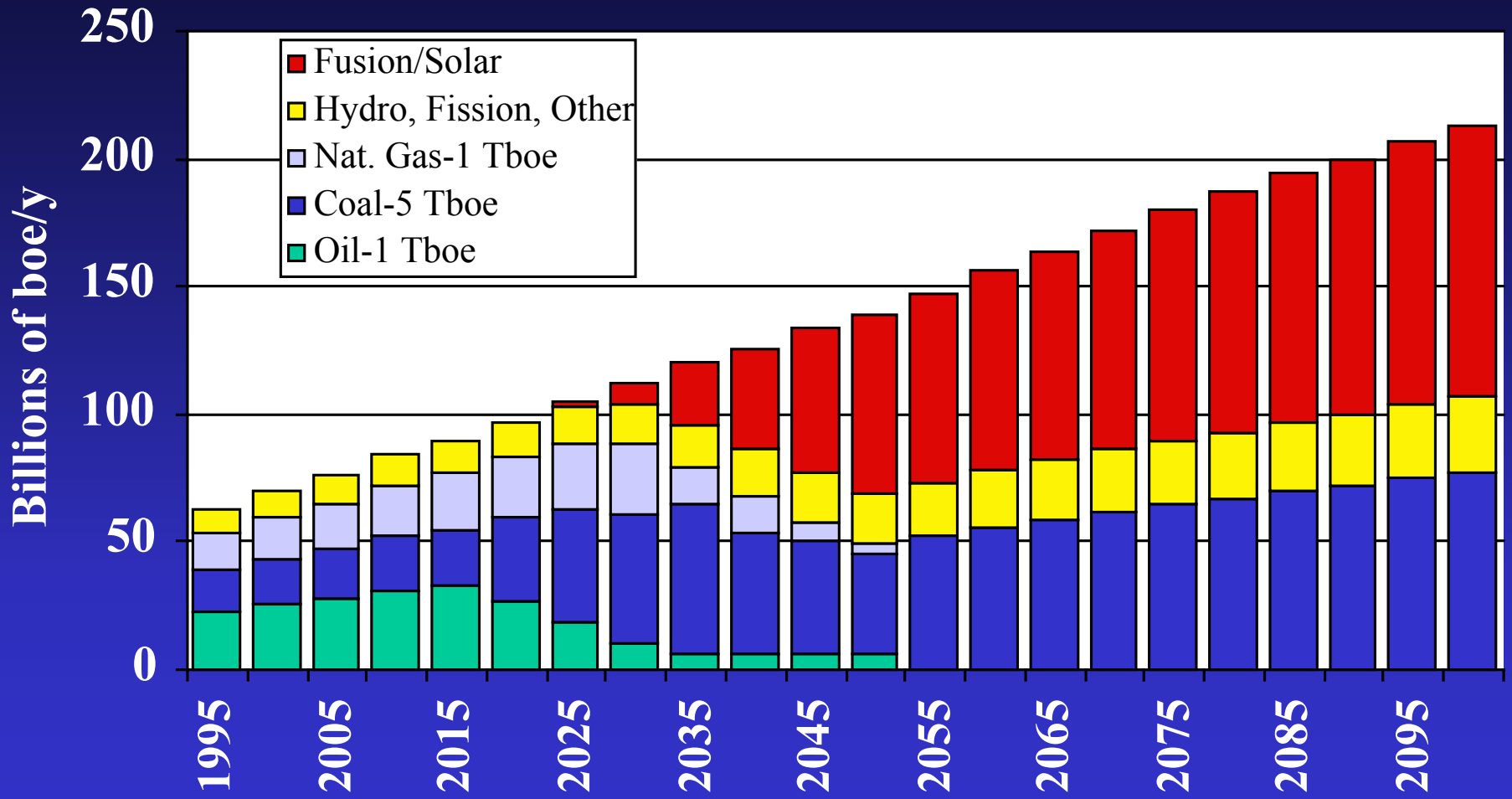
What Are the Major Assumptions in Scenario 2?

- A new energy source (fusion and/or electricity from beamed microwaves) will have the first "commercial" units introduced in 2015
- The penetration of the market will occur at the same rate as fission reactors penetrated the world electric utility market
- The new energy source will mainly replace coal, releasing that fuel for liquefaction or gasification
- The new energy source will saturate the market at ≈50%

The Assumed Penetration of Fusion Energy into the Commercial Market is Somewhat Faster than for Fission in the U.S. and Japan but Considerably Slower than in France



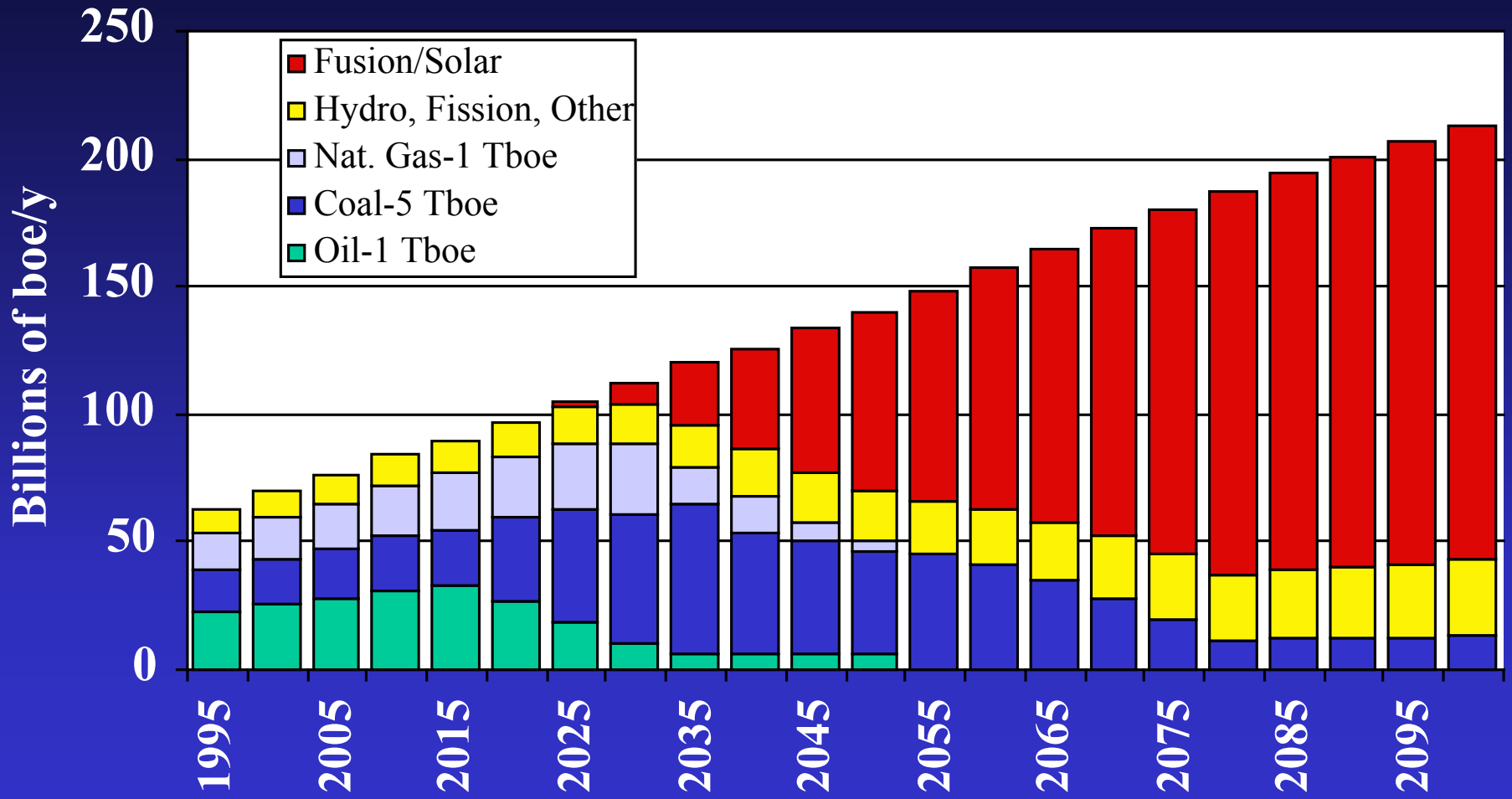
The Introduction of a New Energy Source in 2015 With "Typical" market Penetration at the Expense of Coal Will Leave Some Coal at the End of the 21st Century



What Are the Major Assumptions in Scenario 3?

- A new energy source (fusion and/or electricity from beamed microwaves) will have the first "commercial" units introduced in 2015
- The penetration of the market (up to 2050) will occur at the same rate as fission reactors penetrated the world electric utility market
- The new energy source will mainly replace coal, releasing that fuel for liquefaction or gasification in specialized markets
- The new energy source will saturate the market at ≈50% by 2050, rising to 80% in 2080, then constant at 80%

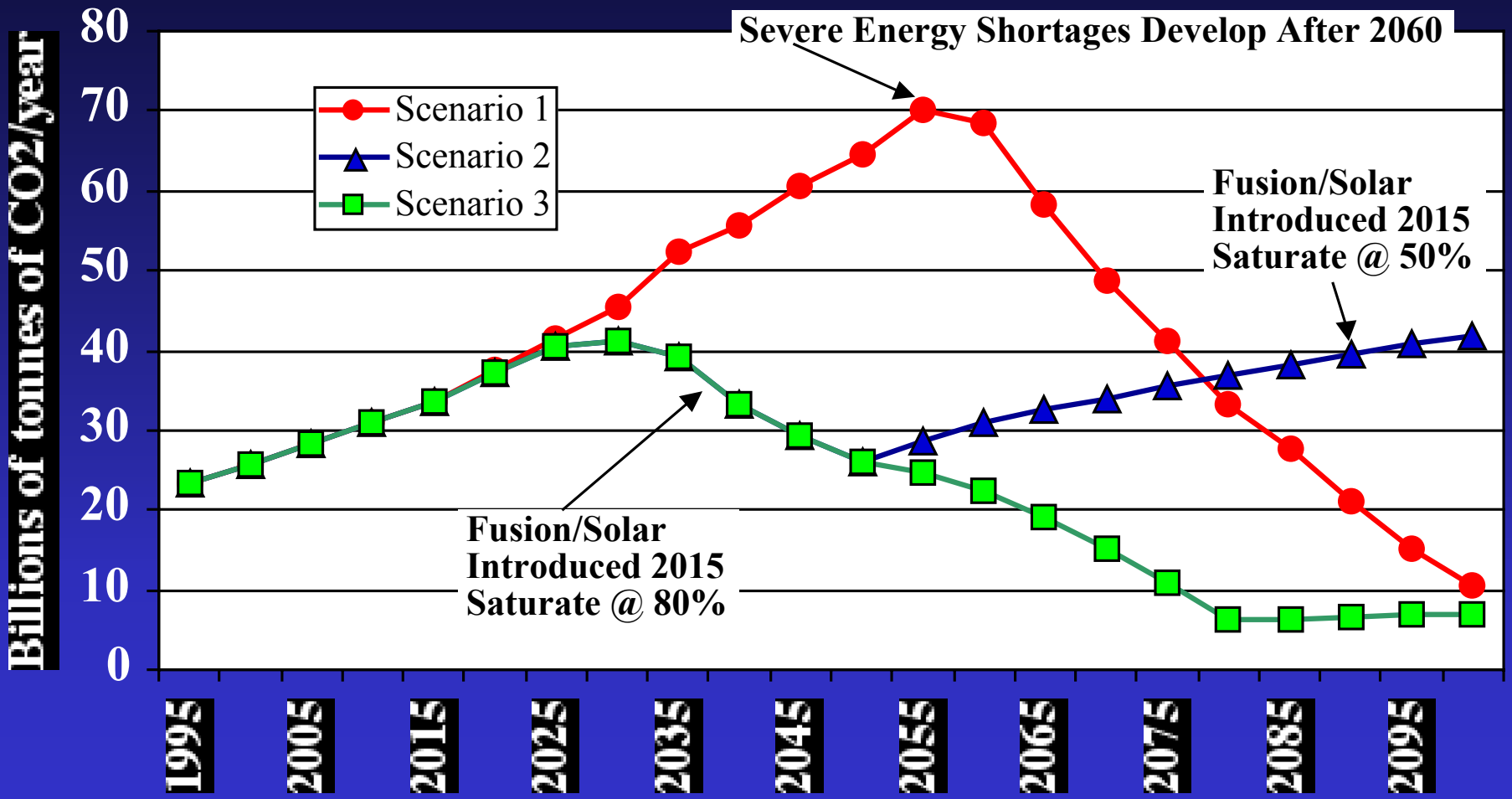
The Introduction of a New Energy Source in 2015 With "Aggressive" Market Penetration at the Expense of Coal Will Leave Considerable Coal at the End of the 21st Century



Implications from Our Three Future Energy Scenarios

	Scenario 1	Scenario 2	Scenario 3
Oil	Present "Reserves" Gone by ≈ 2050		
Natural Gas	Present "Reserves" Gone by ≈ 2050		
Coal	Mostly Exhausted by 2100	Small amount remains-2100	≈ 2 trillion boe left-2100
• Fission • Hydro • Other	Provides 14% of demand (10 bboe-2000 and 30 bboe-2100)		
Gap	Starts≈ 2060, reaches 75% of demand-2100	None	None
• ^{3}He fusion • Beamed Solar	None	Provides 50% by 2050	Provides 80% by 2100

The Only Way to Significantly Reduce Greenhouse Gas Emissions in the 21st century is to Introduce a Non Polluting Energy Source by ≈ 2015



The Impact of an Advanced Fusion/SPS Economy on CO_2 Emission Can be Significant

- There is probably nothing that can be done about a doubling of the annual emission rate of CO_2 for the next 30 years.
- In the "present mix" scenario, the annual CO_2 emission rates could triple by 2060.
- The introduction of ^3He fusion/SPS in 2015 could hold the annual CO_2 emission rates to twice the current level if fusion/SPS can capture ≈50% of the energy market after 2050.
- If ^3He fusion/SPS can capture up to 80% of the market by 2080, the CO_2 emission rates can be reduced to 1/3 the present levels.