

Resource Limitations on Earth- Energy

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Energy is essential for our health, economy, and safety.

We Need Energy to Live in Today's World

Electricity



Liquid Fuels



Heat



Outline of Lecture on Energy

- Definitions of Power and Energy Units
- Historical Energy Use
 - a) World
 - b) United States
- Current Energy Use Patterns
- Projected Energy Use
 - a) World
 - b) United States
- Consequences of Dependence on Fossil Energy
- World Energy Resources
 - a) Fossil
 - b) Nuclear
 - c) Renewables
- What Energy Resources in Space?

Summary of Frequently Used Energy Units

Unit	Definition
Joule (J)	Work Done by the Force of 1 Newton Acting Over a Distance of 1 m. (Also = 10^7 ergs)
British Thermal Unit (BTU)	The Amount of Energy Needed to Raise 1 Pound of Water by 1 °F
QUAD	10^{15} BTU's
kilocalorie (kcal)	Energy Required to Raise 1 kg of Water 1°C
(mtce)	Metric Tonne of Coal Equivalent
(boe)	Energy Equivalent of a Barrel of Oil
mtoe	Metric Tonne of Oil Equivalent
m ³ gas	Cubic Meter of Natural Gas @ Standard Temperature and Pressure - 1 atm. and 273 °K.
ft ³ gas	Cubic Foot of Natural Gas @ Standard Temperature and Pressure - 1 atm. and 273 °K.

Conversion Table for Energy Units

	Joules	BTU	Quads	kcal	mtce	boe	mtoe	m3 gas	ft3 gas	kWh	TWy
1 J =		9.479 E-4	9.479 E-19	2.39 E-3	3.414 E-11	1.634 E-10	2.234 E-11	2.684 E-8	9.48 E-7	2.78E-7	3.171 E-20
1 BTU =	1055		1 E-15	0.2522	3.602 E-8	1.724 E-7	2.357 E-8	2.832 E-5	0.001	2.93E-4	3.345 E-17
1 QUAD =	1.055 E+18	1 E+15		252 E+12	3.602 E+7	1.724 E+8	2.357 E+7	2.832 E+10	1 E+12	2.93E+11	0.03345
1 kcal =	4184	3.966	3.966 E-15		1.429 E-9	6.838 E-7	9.347 E-8	1.123 E-4	3.966 E-3	1.16E-3	1.327 E-16
1 mtce =	29.29 E+9	27.76 E+6	27.76 E-9	7 E+6		4.786	0.6543	786.1	2.776 E+4	8,135	9.287 E-10
1 boe =	6.119 E+9	5.8 E+6	5.8 E-9	1.462 E+6	0.2089		0.1367	164.2	5800	1,699	1.94 E-10
1 mtoe =	44.76 E+9	42.43 E+6	42.43 E-9	1.07 E+7	1.528	7.315		1201	42,430	12,430	1.94 E-4
1 m3 gas =	37.26 E+6	35.31 E+3	35.31 E-12	8905	1.272 E-3	6.089 E-3	8.323 E-4		35.31	10.35	1.181 E-12
1 ft3 gas =	1.055 E+6	1000	1 E-12	252.2	3.6 E-5	1.724 E-4	2.357 E-5	0.02832		0.2930	3.345 E-14
1 kWh =	3.60E+6	3.41E+3	3.41E-12	860.39	1.228 E-4	5.88E-4	8.042E-05	0.096621	3.412		1.142E-13
1 TWy =	3.154 E+19	2.989 E+16	29.89	7.537 E+15	1.076 E+9	5.154 E+9	7.045 E+8	8.464 E+11	2.989 E+13	8.76E+12	

What is the Significance of the Energy in One Barrel of Oil

- It can produce 1,700 kWh of heat ($\approx 550 \text{ kWh}_e$)
 - *This is enough to run a 1,500 W hair dryer for ≈ 1 h every day for a year*
 - *This enough to provide 2.6 h of electricity to the ME building*
 - *This is enough to provide ≈ 30 s of electricity to the Madison Campus*
- It is equal to the energy in 200 kg of coal
- It is equal to the energy in 5,800 ft³ (164 m³) of natural gas
- It can produce 18 days of electricity for the average U. S. citizen
- It can power an average automobile in the U. S. for 1,000 miles (the distance driven by the average car in the U. S. in 33 days)
- It can provide the energy consumed by the average American in 6.6 d.

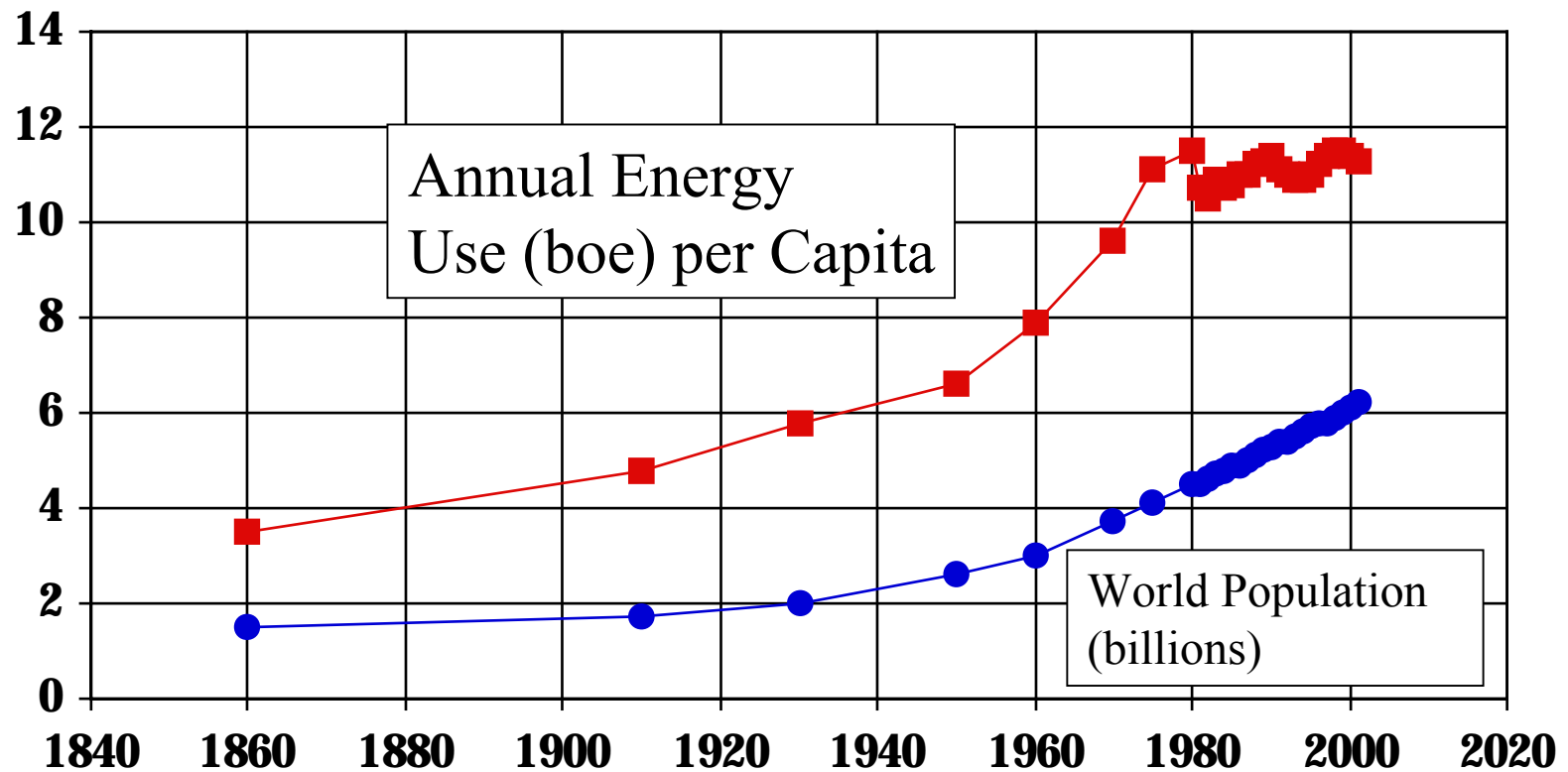
The World Energy Demand is the Product of Two Simple Numbers



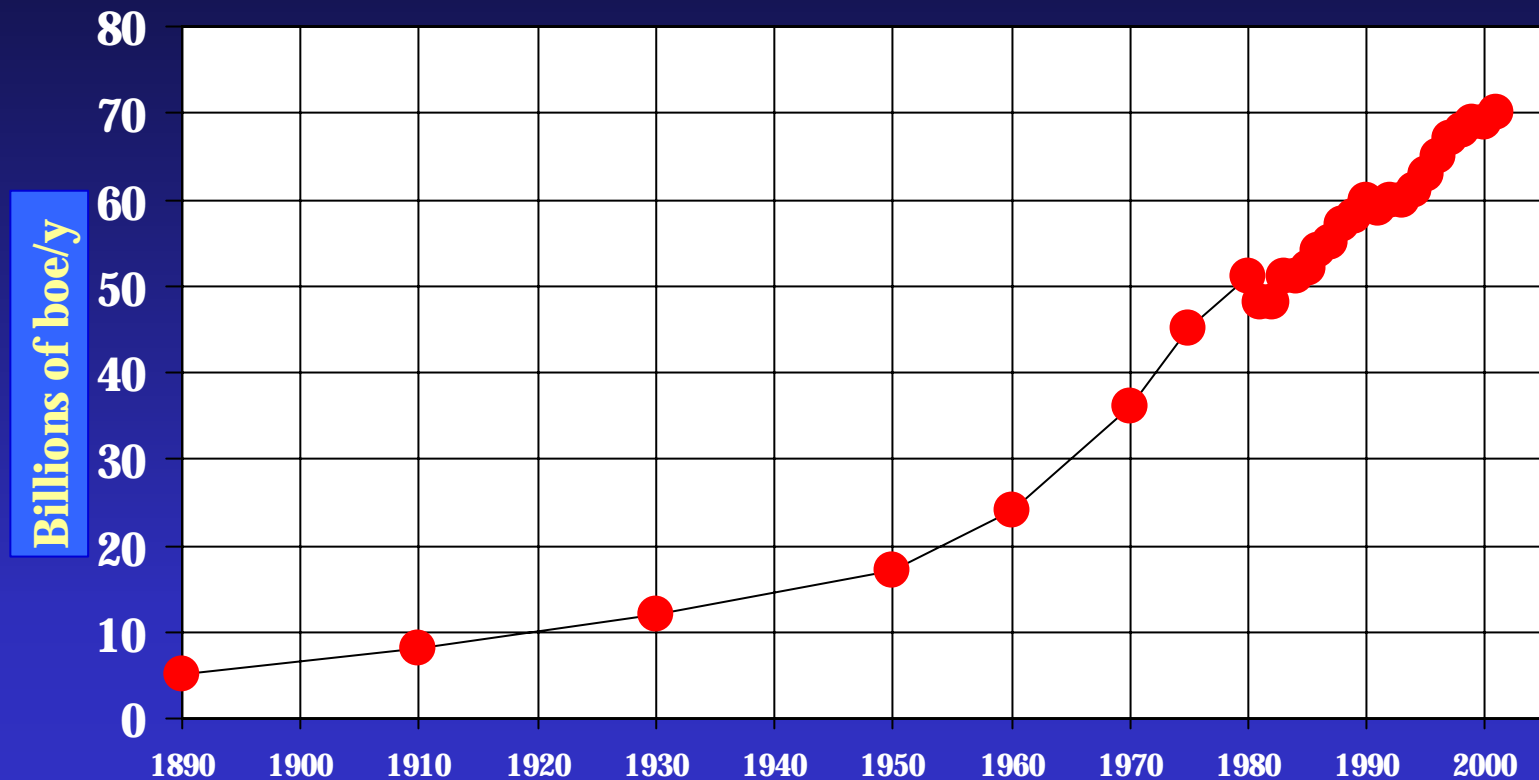
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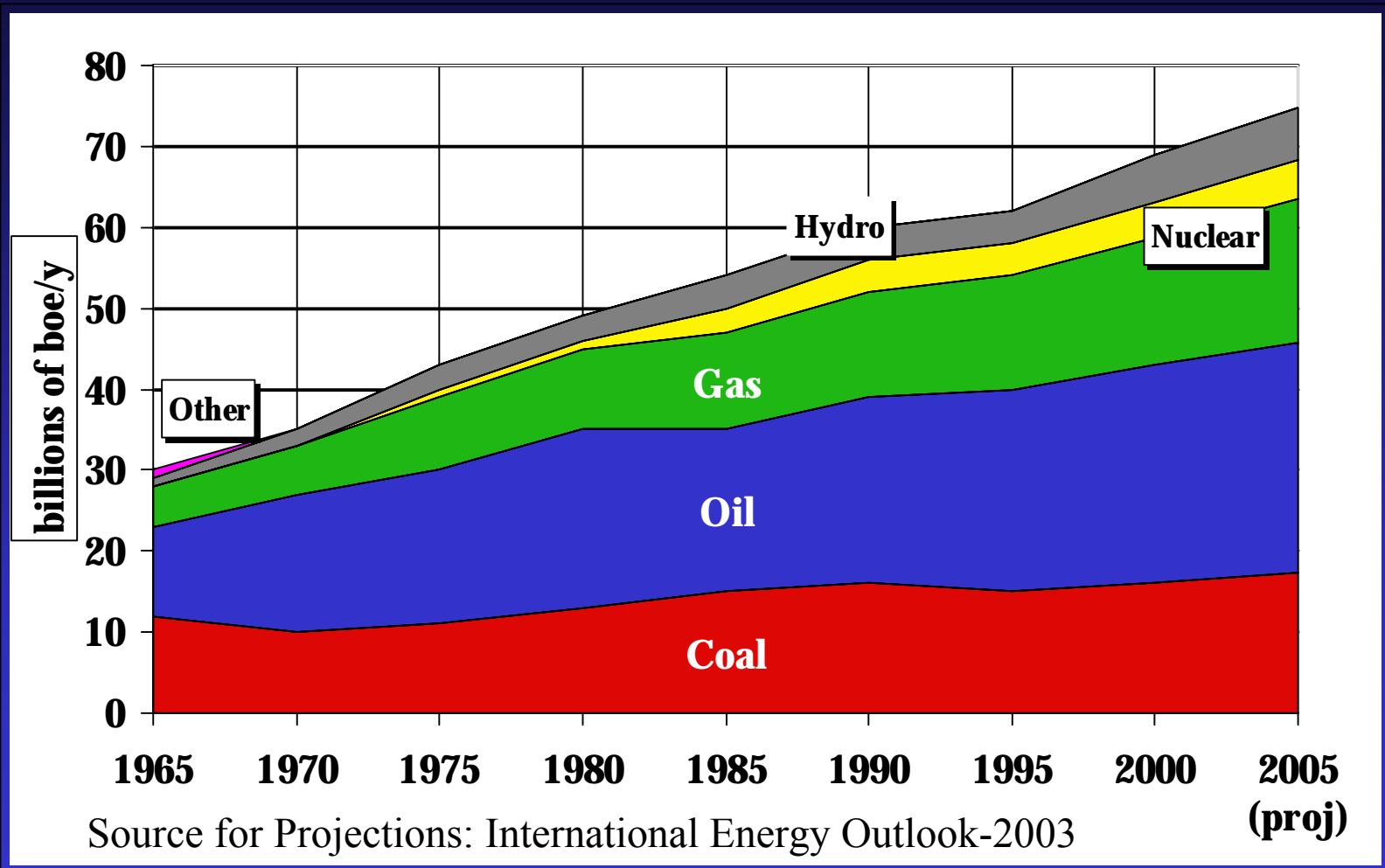
The World Energy Use Per Capita Has Been Essentially Constant Since the Oil Crisis of 1973 But the Population continues to Increase



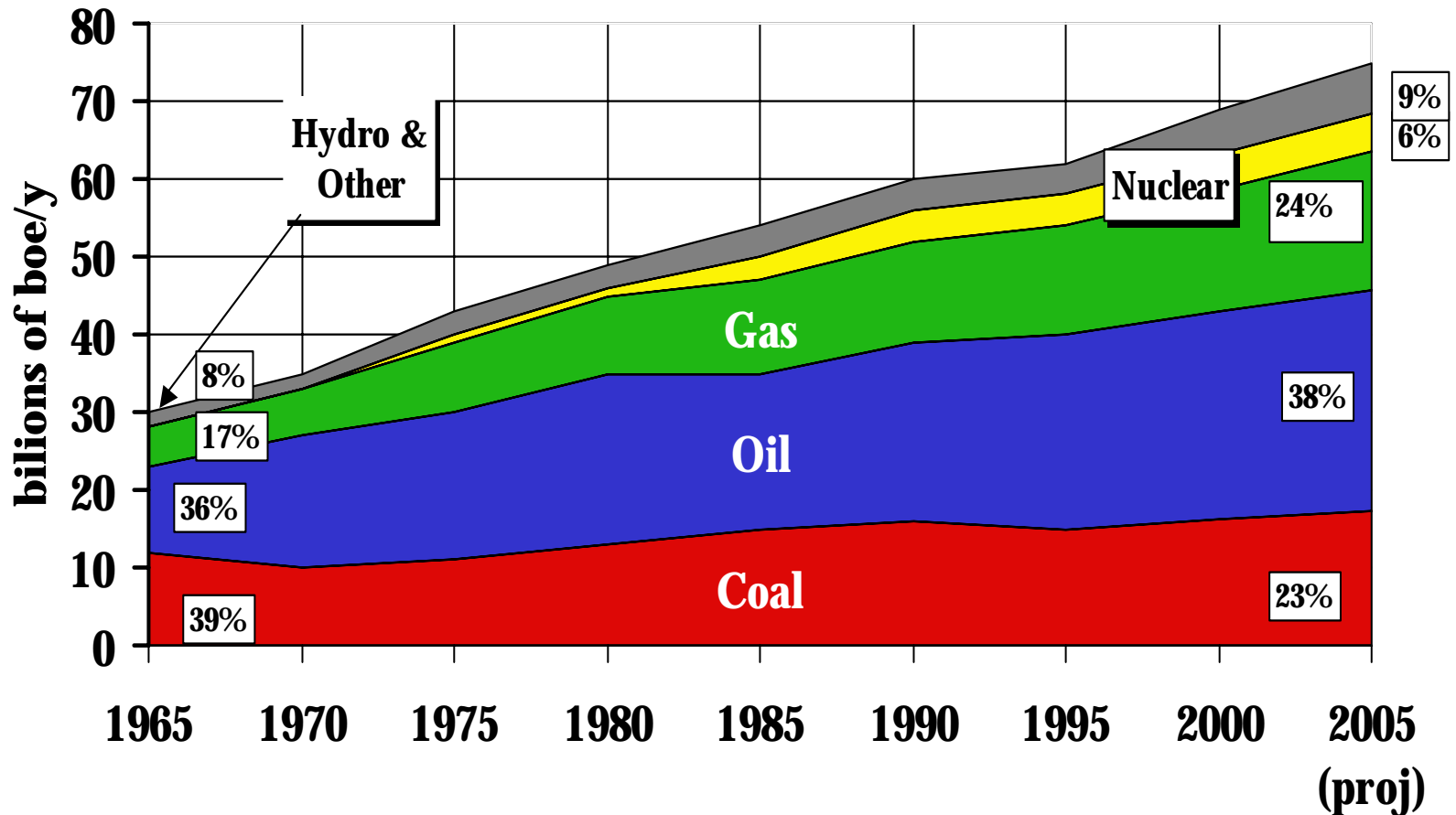
The Total Energy Use in the World Has Increased by Over a Factor of 4 Since World War II



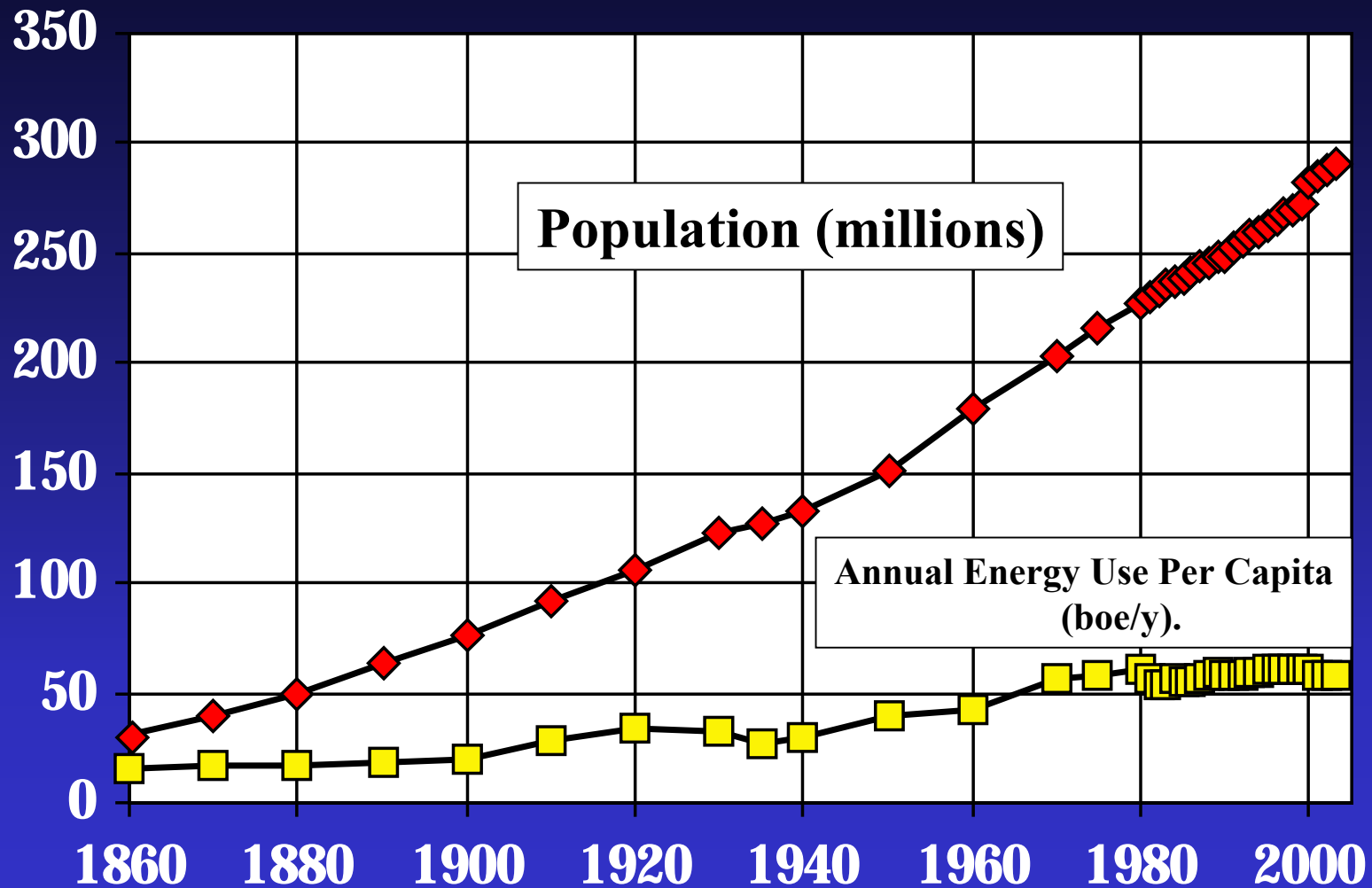
Fossil Fuels Still Account for Over 85% of the Primary Energy Consumed in the World



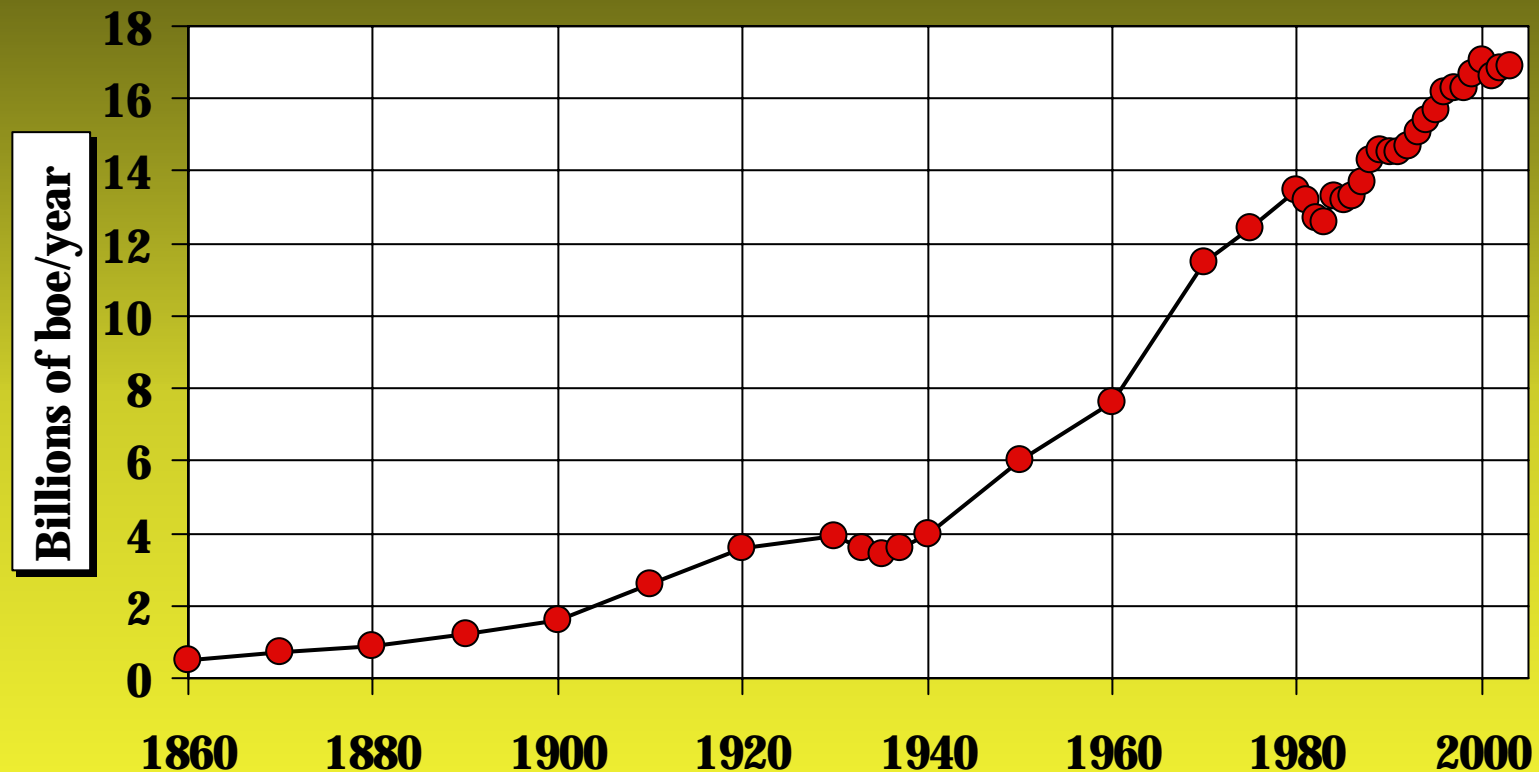
Fossil Fuels Still Account for Over 85% of the Primary Energy Consumed in the World



Although the U. S. Energy Use Per capita Has Been Relatively Constant Since the Oil Crisis of 1973, the Increase in Population has Pushed up the Energy Consumption

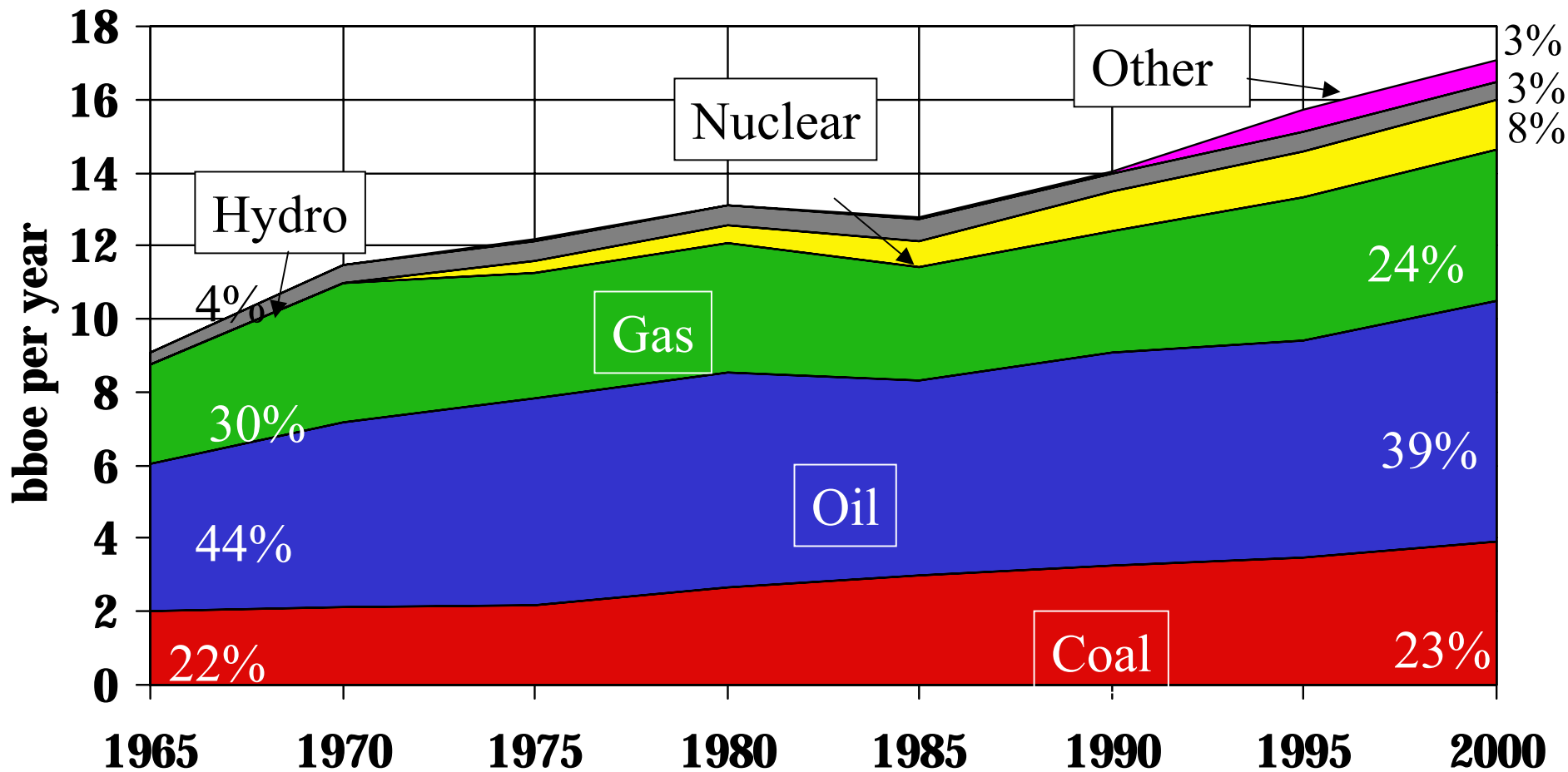


The Total Energy Use in the U. S. Has Increased by a Factor of 4 Since World War II

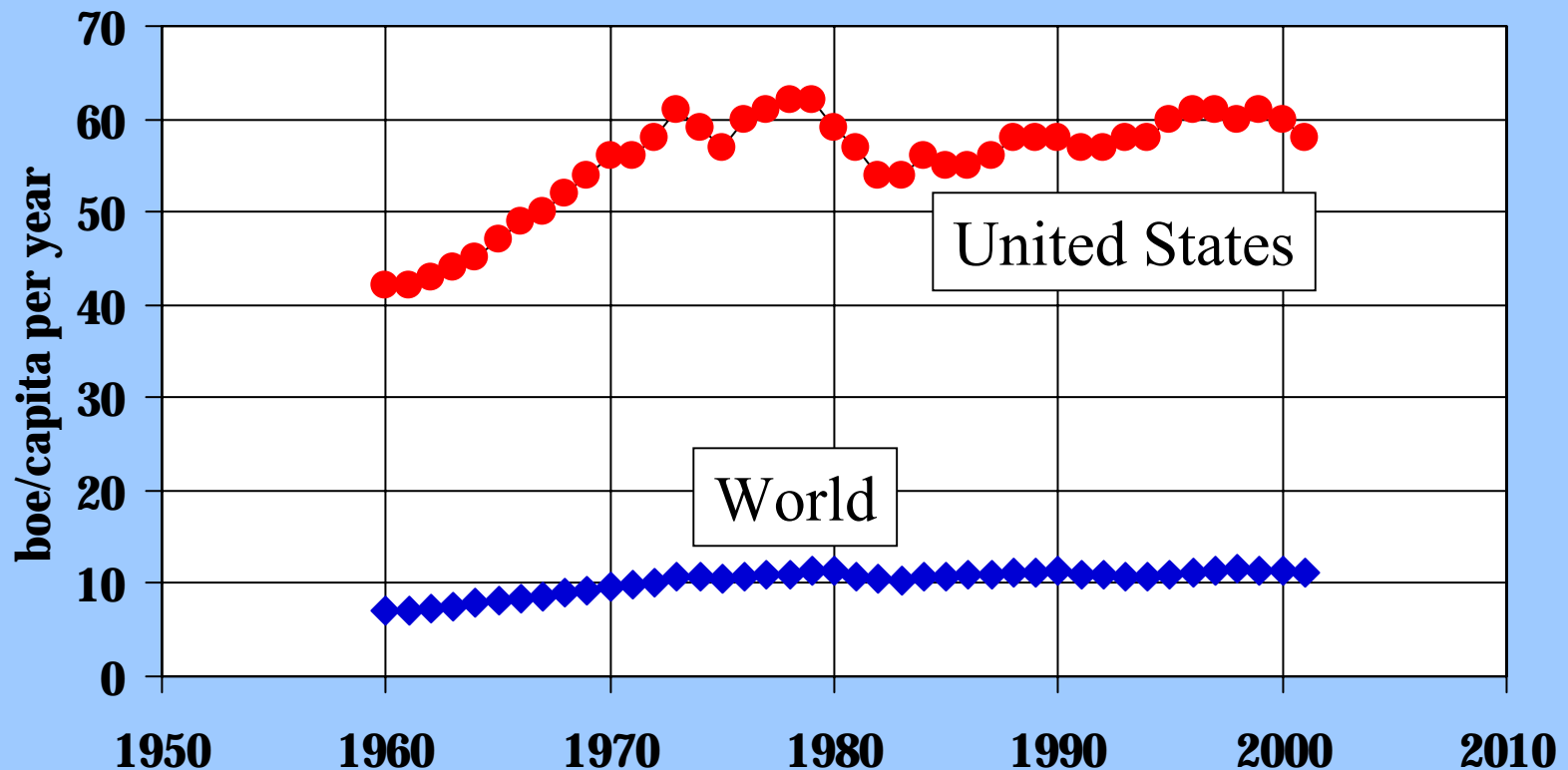


Source of Data Since 1973-Monthly Energy review-December, 2003, DOE/EIA-0035(2003/12)

Fossil Fuels Still Account For 89% of the Primary Energy Consumed in the United States

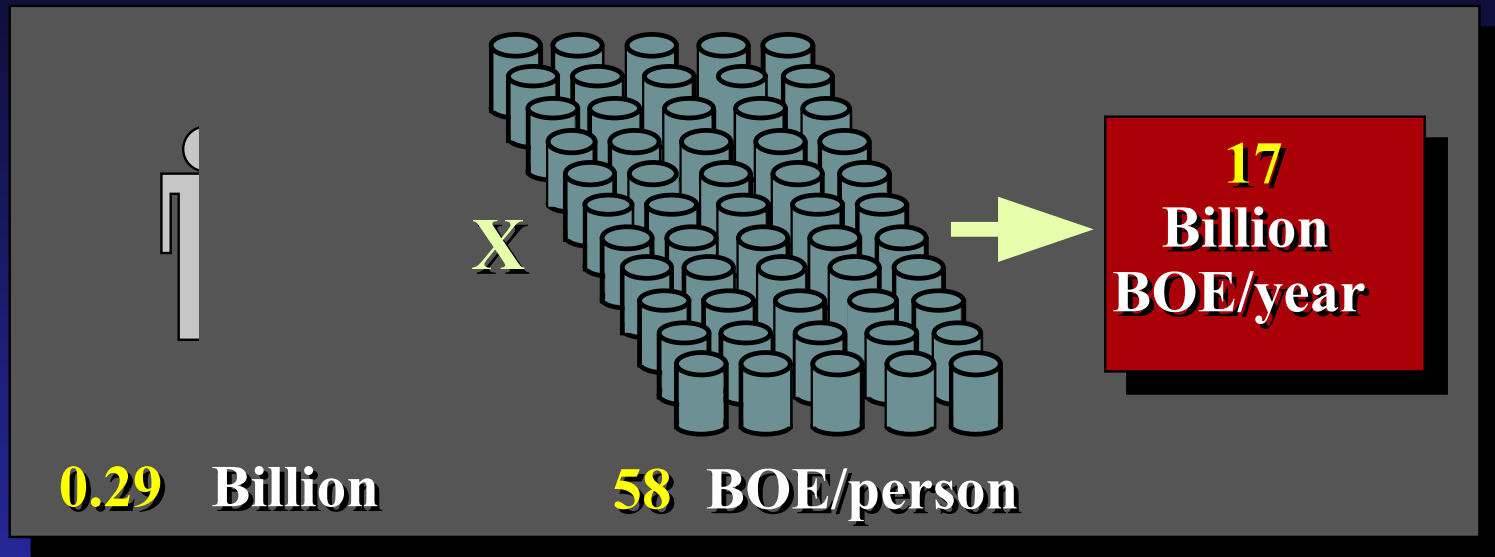


The U. S. Continues to Use a Large Amount of Energy Per Capita

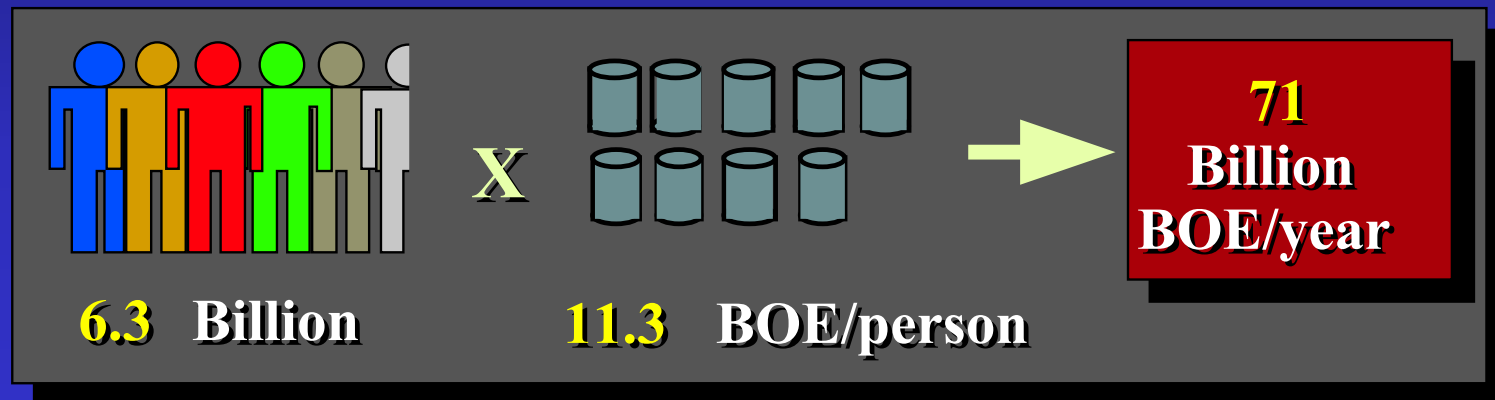


The Energy Use per Person in the U.S. is Much Larger Than in the Rest of the World

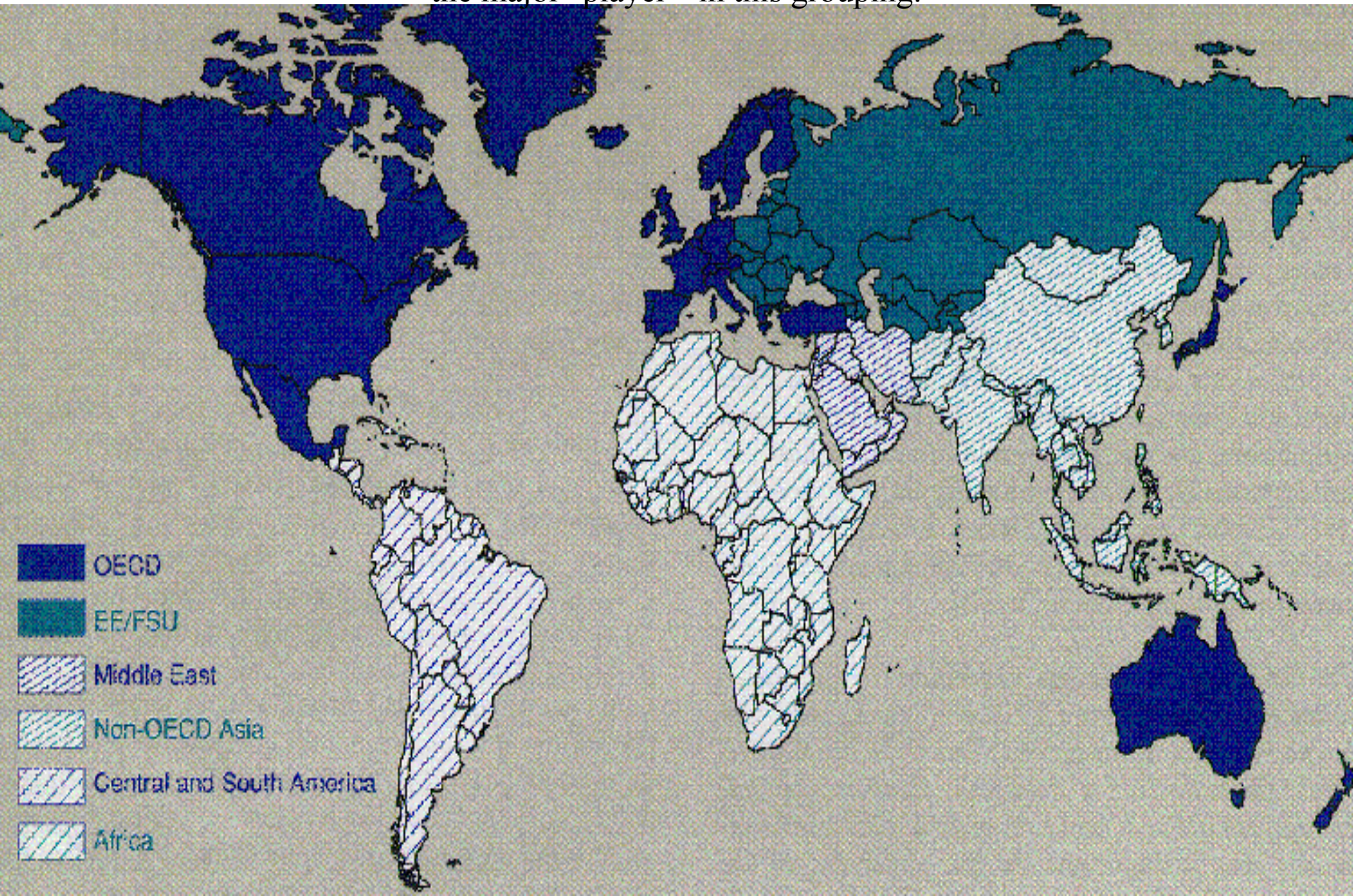
United States



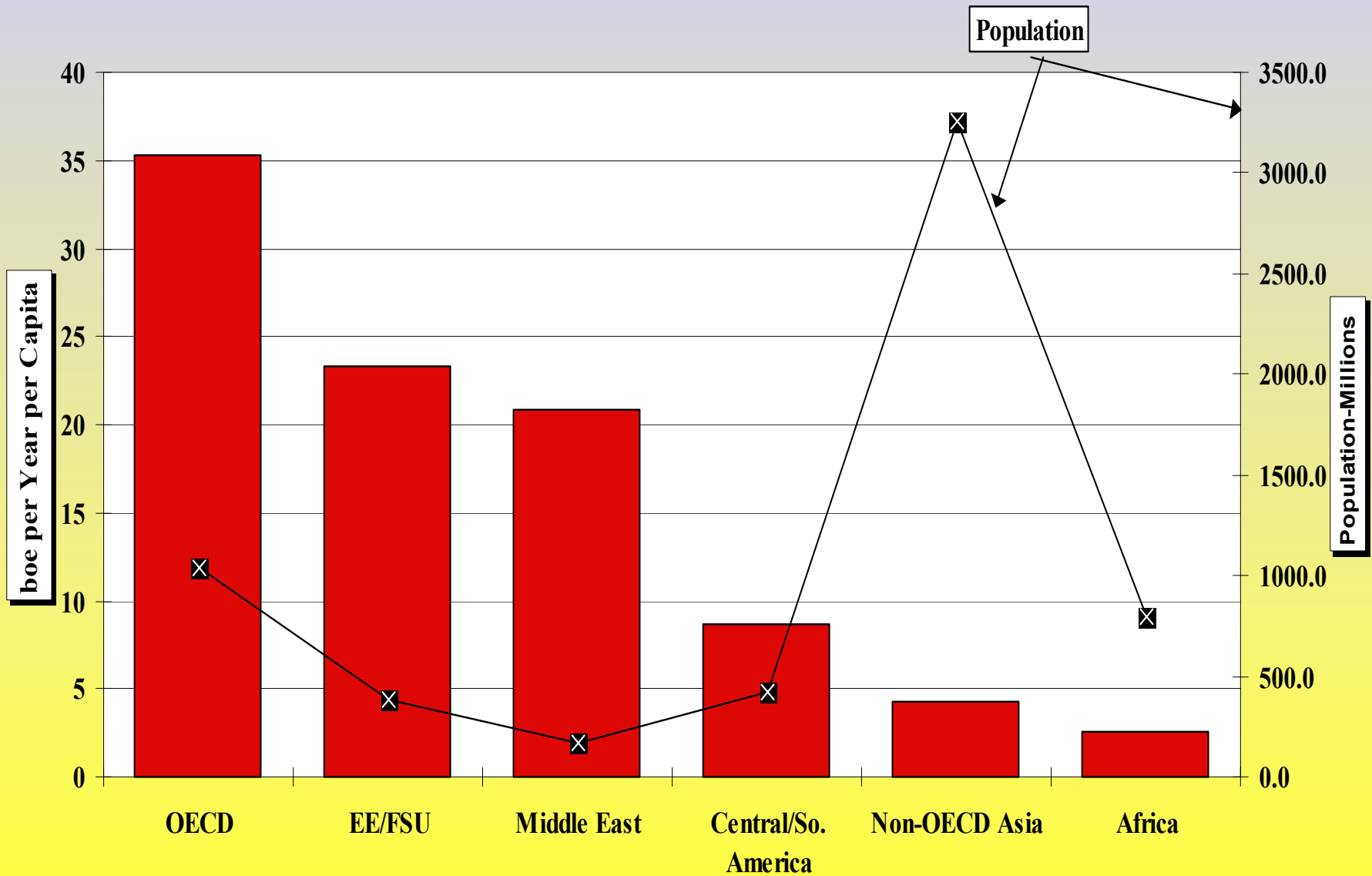
Rest of the World



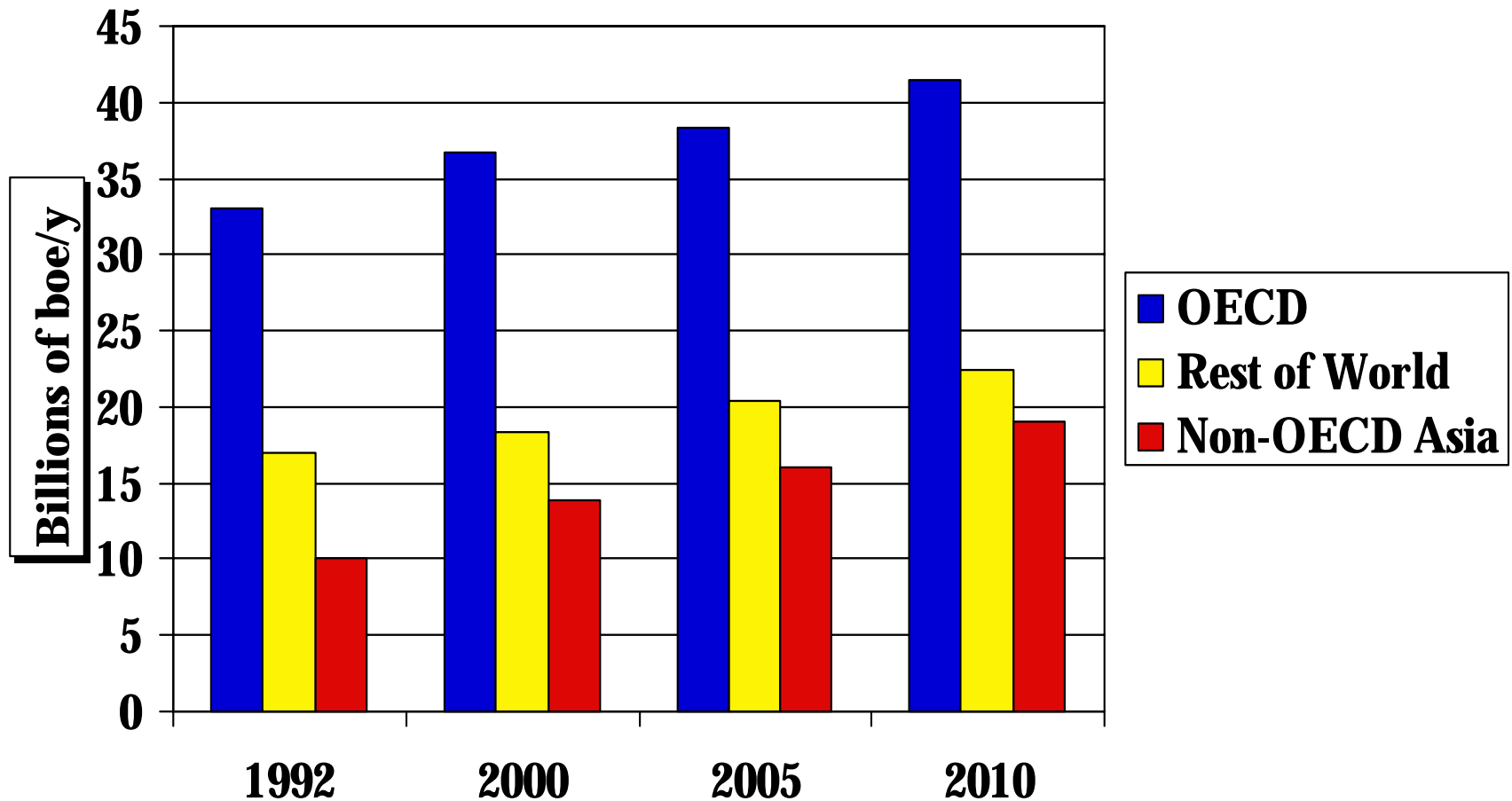
The World can be conveniently broken up into 6 groups of countries according to location and economic strength. The Organization for Economic Co-operation and Development (OECD) is the major "player" in this grouping.



In 2000 the OECD Nations Comprised Only 17% of the World's Population But Consumed 53% of the World's Energy

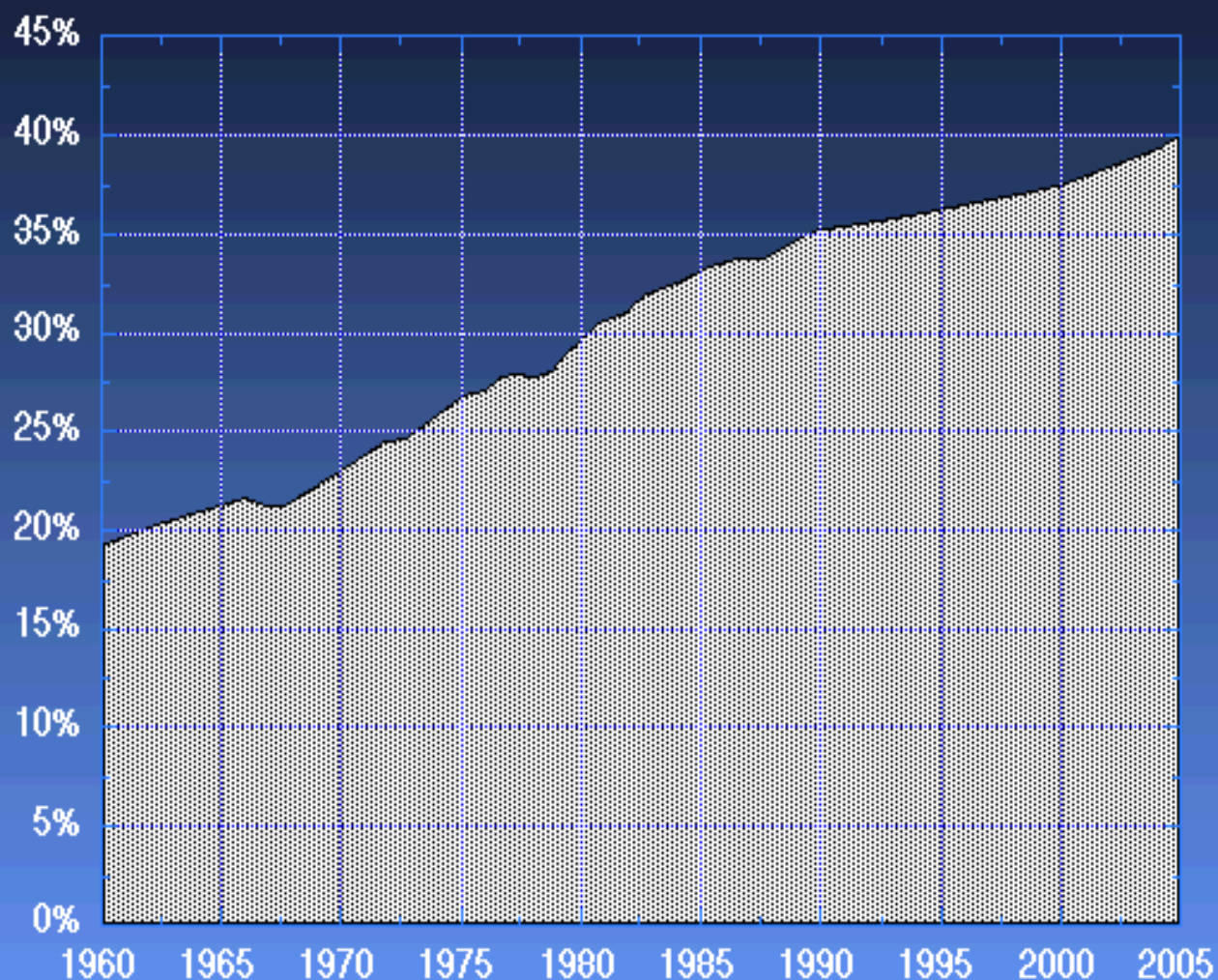


Over the Next 10 Years the Energy Consumption of the Non-OECD Asian Nations is Projected to Increase at 3-4 Times the Rate of the OECD Nations



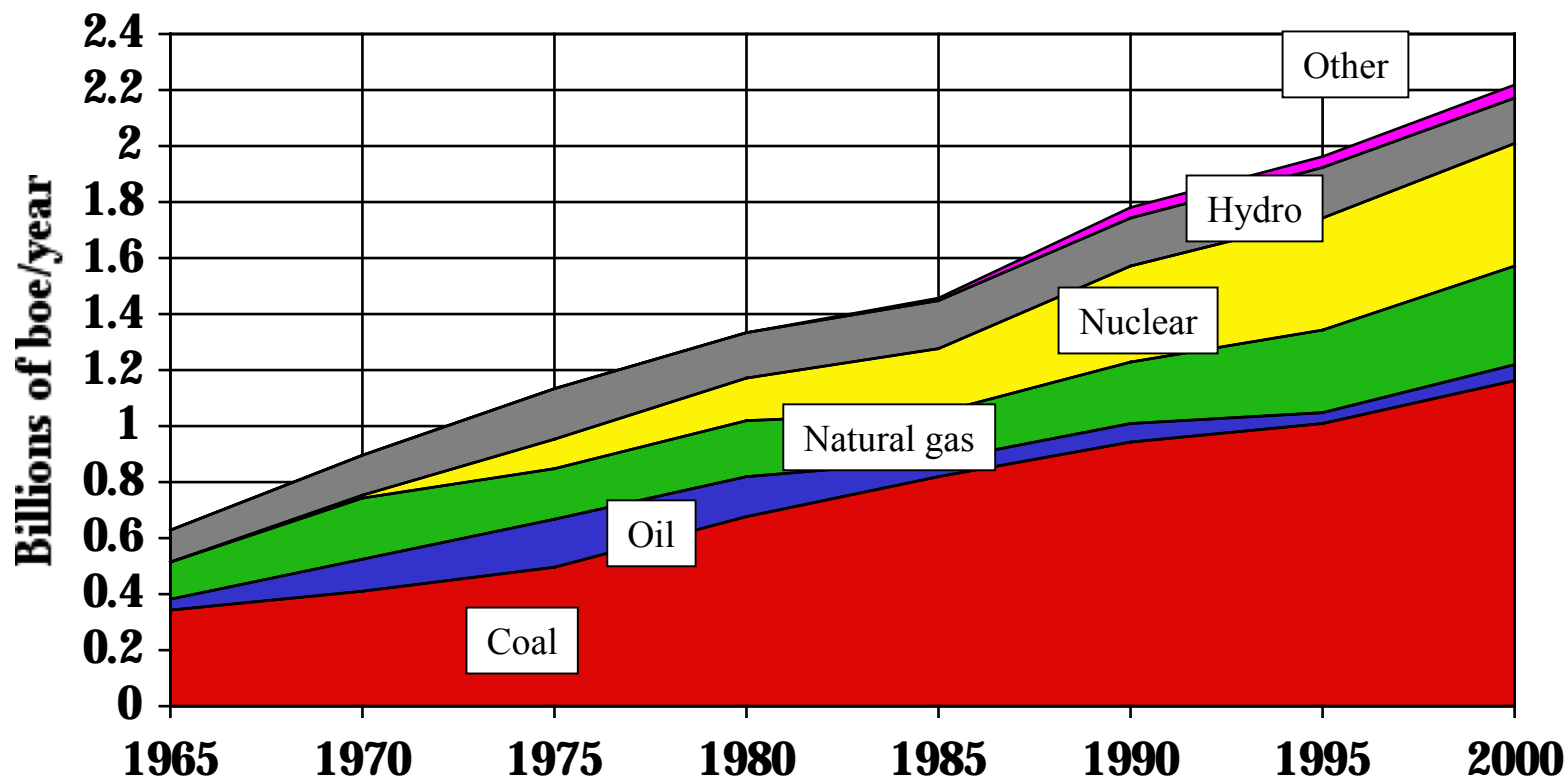
Source: International Energy Outlook-2003

Electricity's Share of OECD Total Primary Energy Supply is Increasing



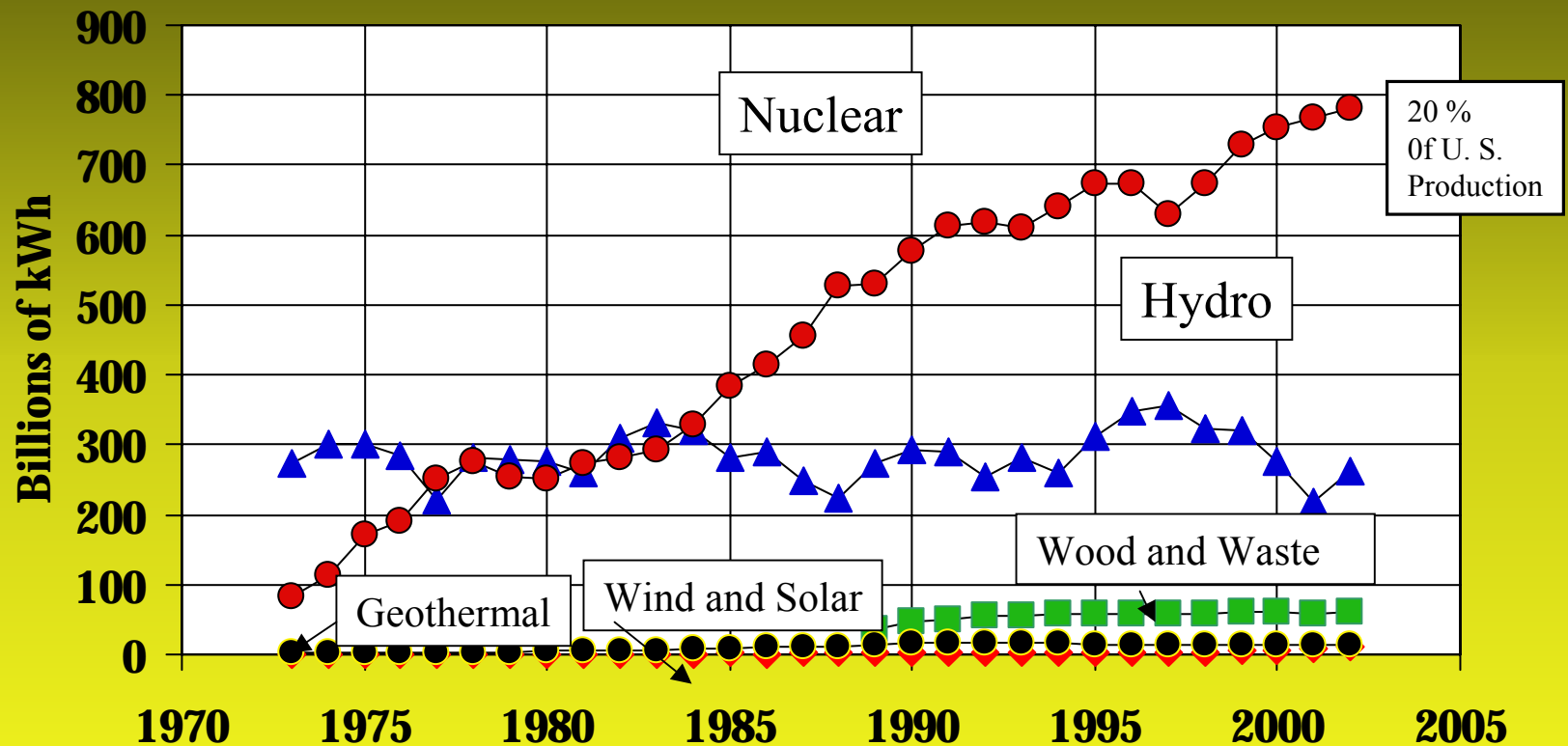
Source: IEA Secretariat

Fossil Fuels Still Produce 2/3's of the Electricity Consumed in the United States



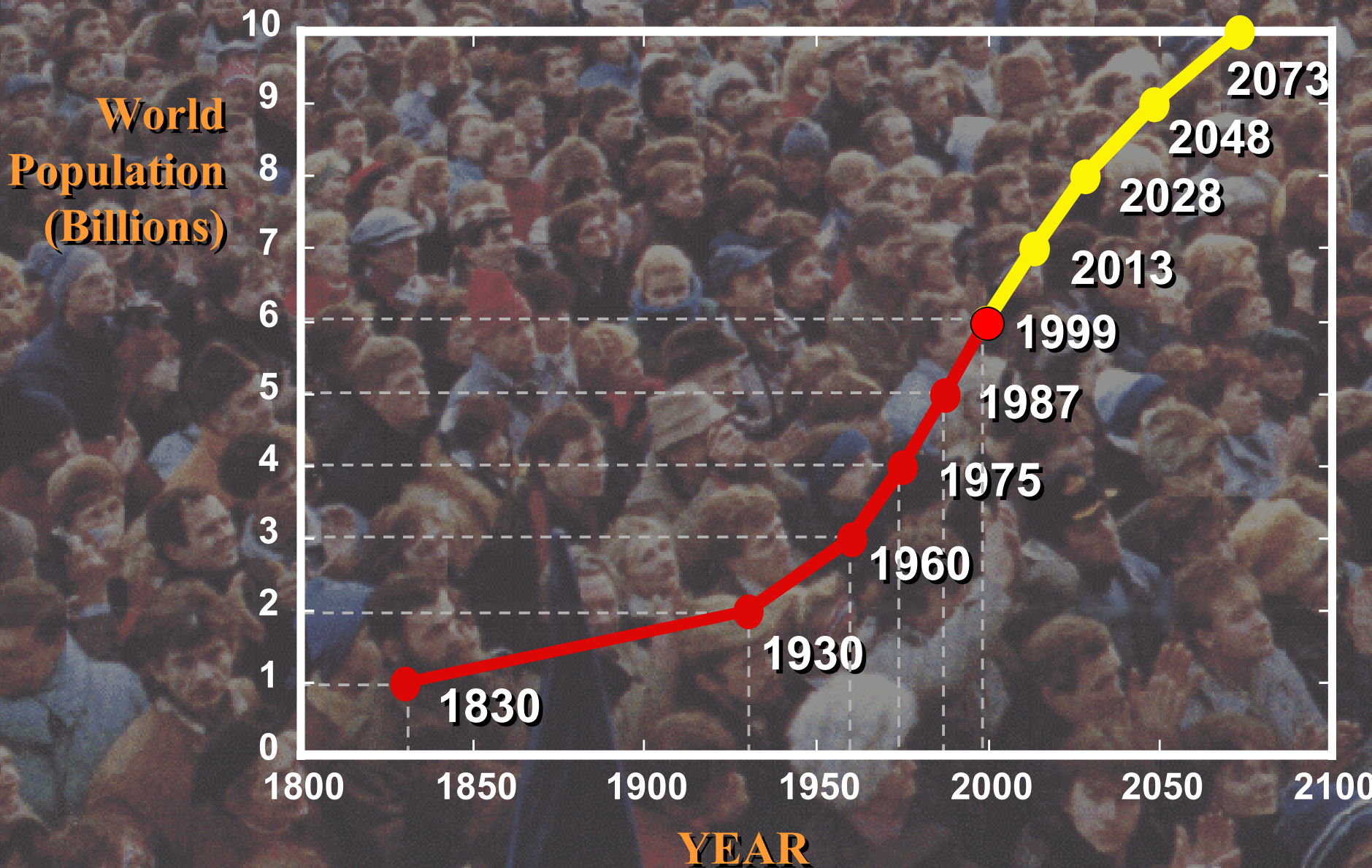
Source: Annual Energy Review-2000, DOE/EIA-4444 (2000)

Nuclear Power Continues to Outstrip the Non-Fossil Fuels in Generation of Electricity in the United States

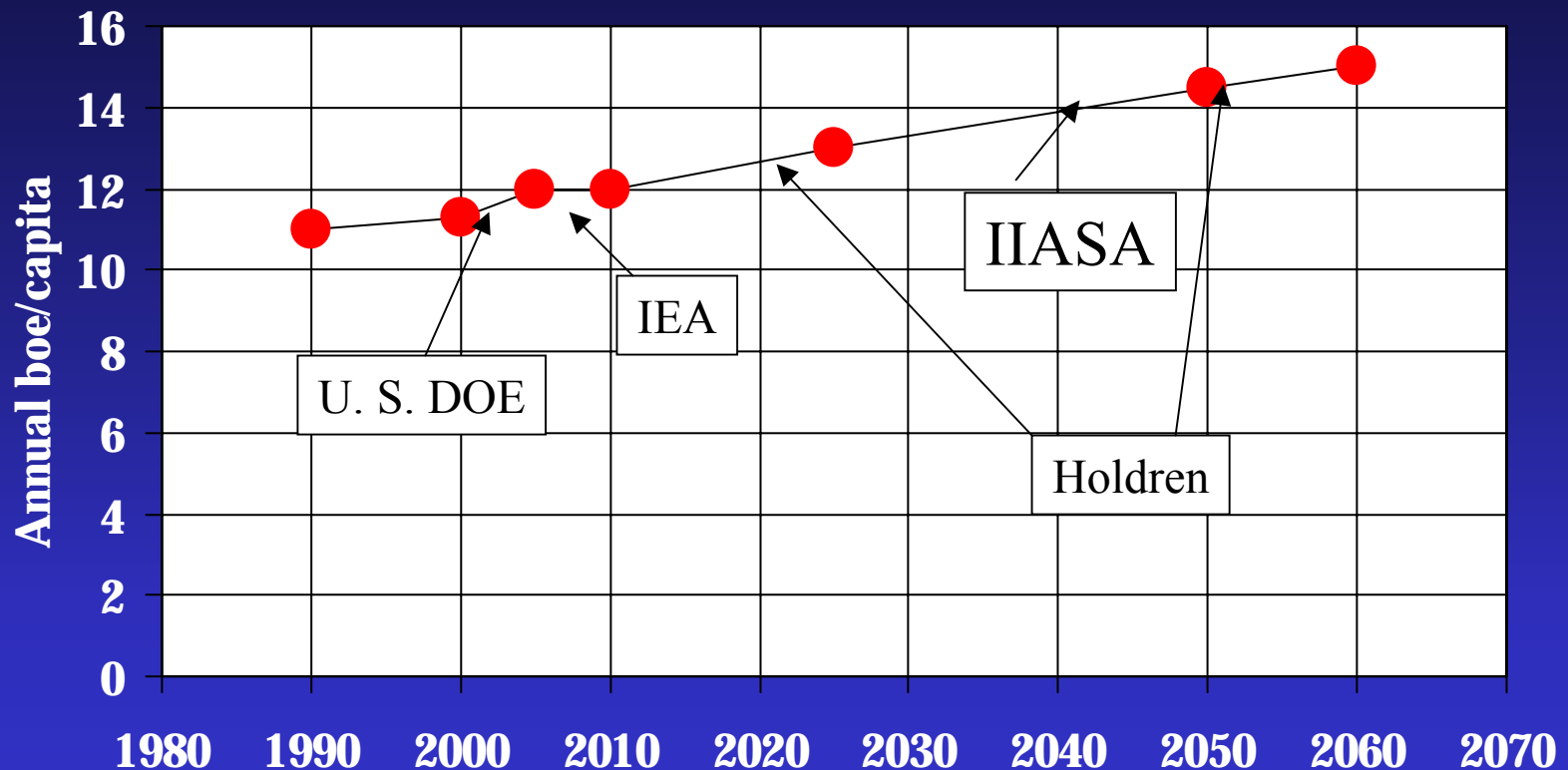


Source: Monthly Energy Review Dec-2003, U. S. Dept. of Energy, DOE/EIA-0035(2001/12)

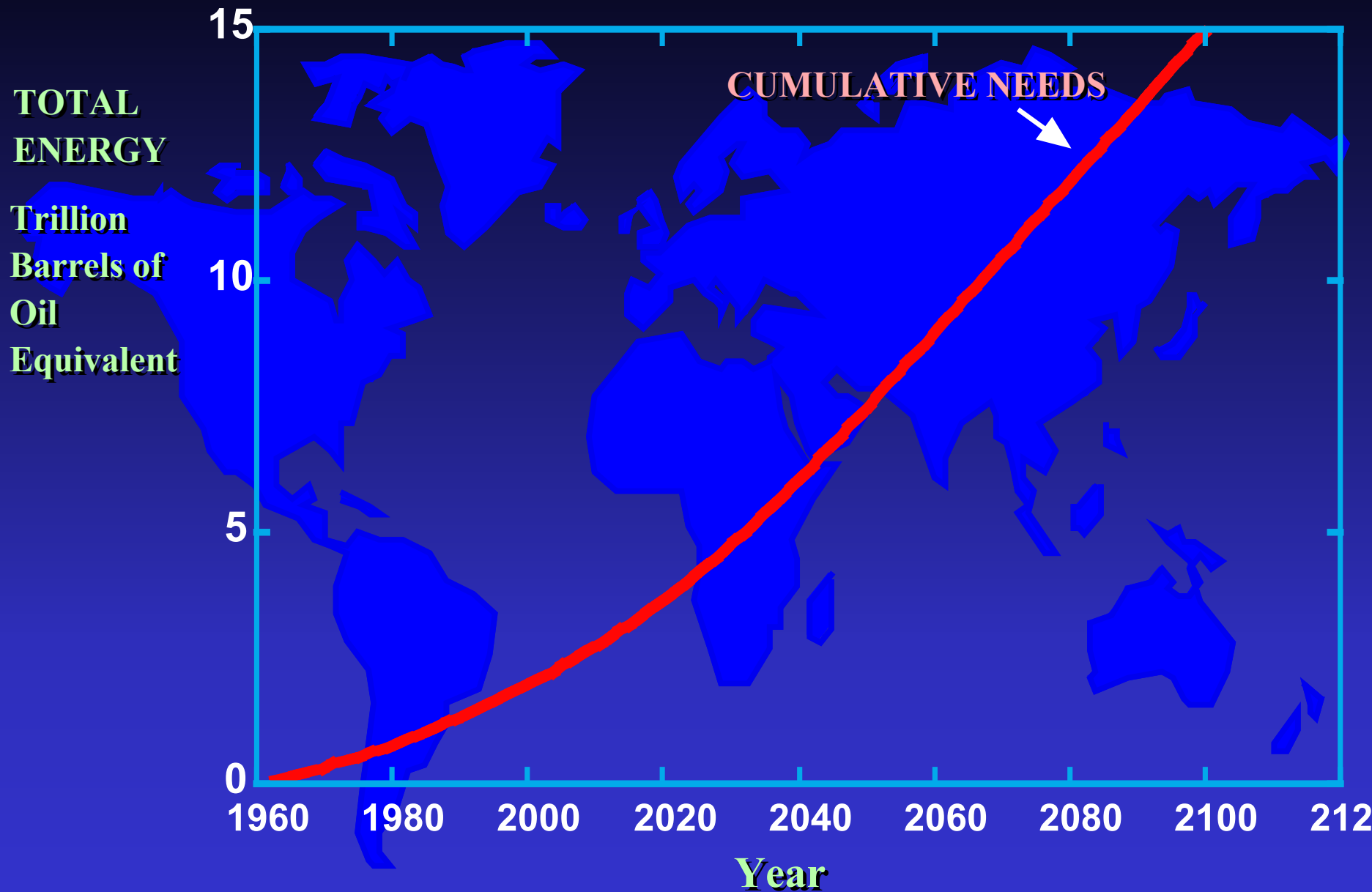
World Population Growth Past and Future



The Annual Per Capita Energy Use Rate is Predicted to Rise to 15 boe by the Middle of 21st Century Mainly Because of Increased Energy Use in Non-OECD Asia

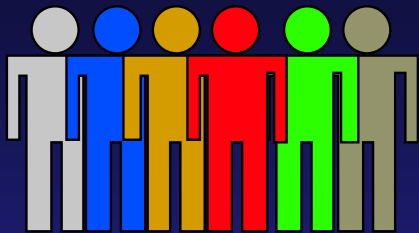


World Energy Consumption and Resources for the Future



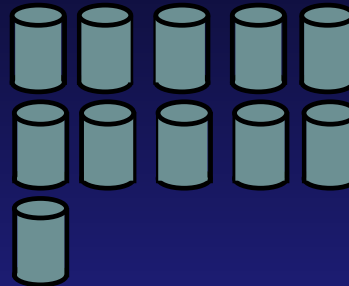
World Energy Needs

Present



6.3 Billion

X

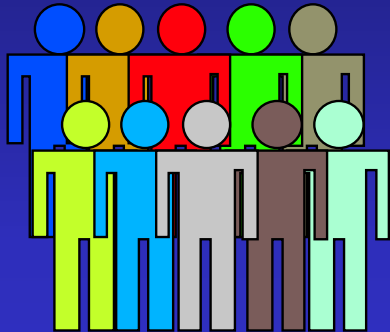


**11.3 barrels/
capita**



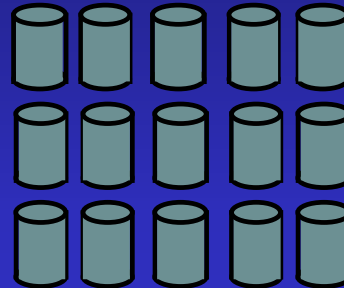
**71
Billion
BOE/year**

Future

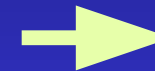


10 Billion

X

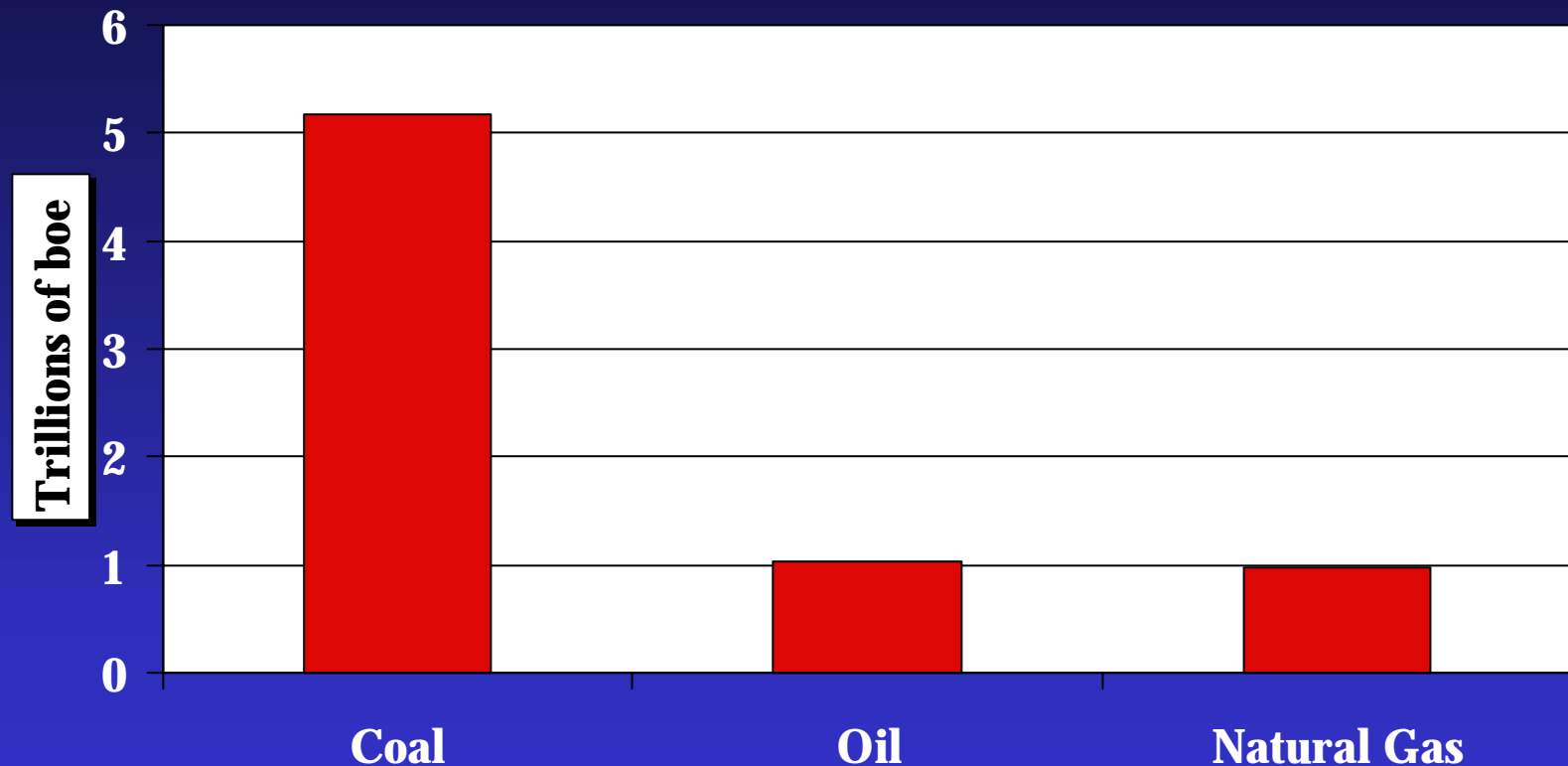


**15 barrels/
capita**



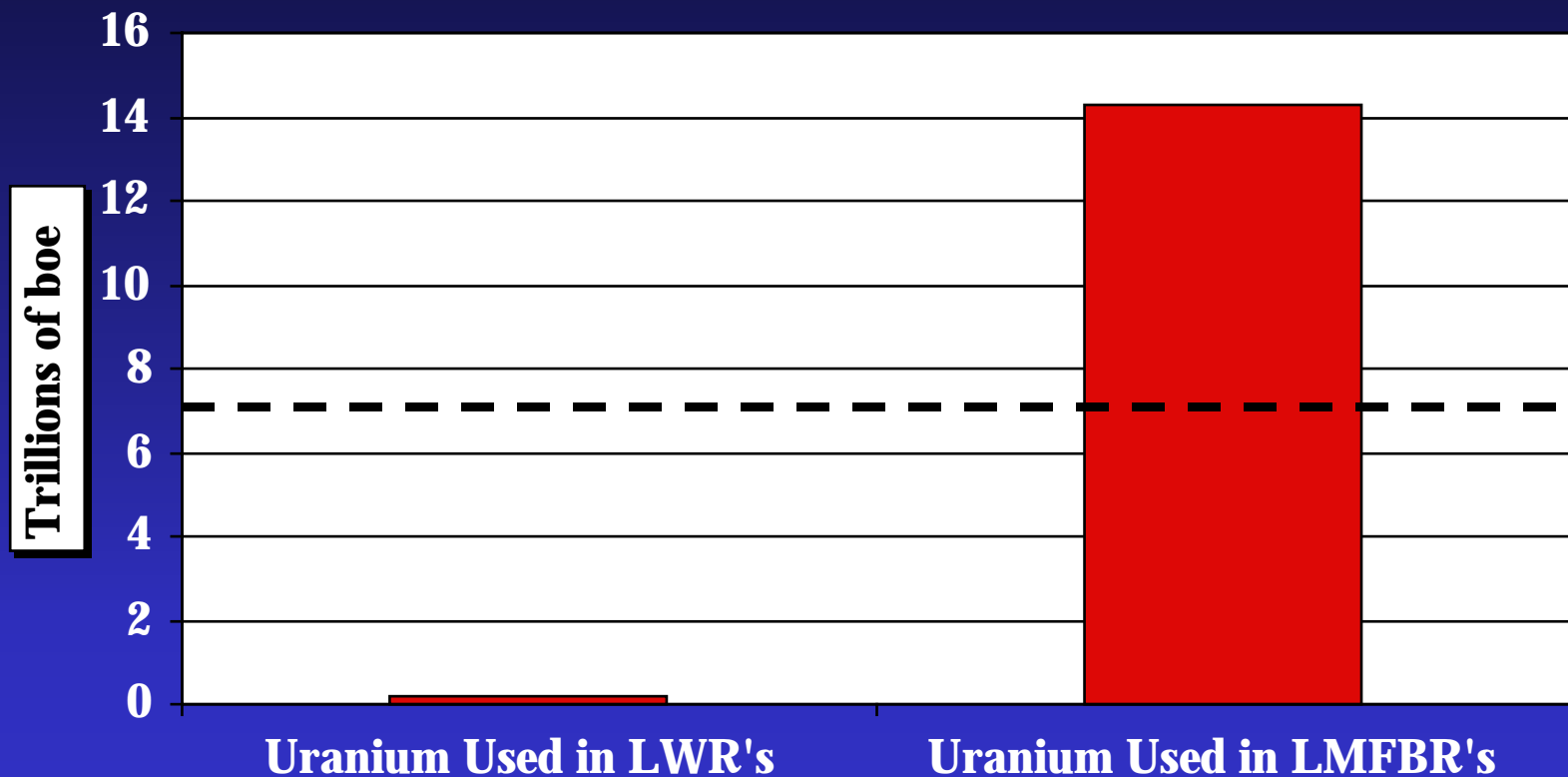
**150
Billion
BOE/year**

The World Reserves of Fossil Fuel are Dominated by Coal (January 1, 2002)



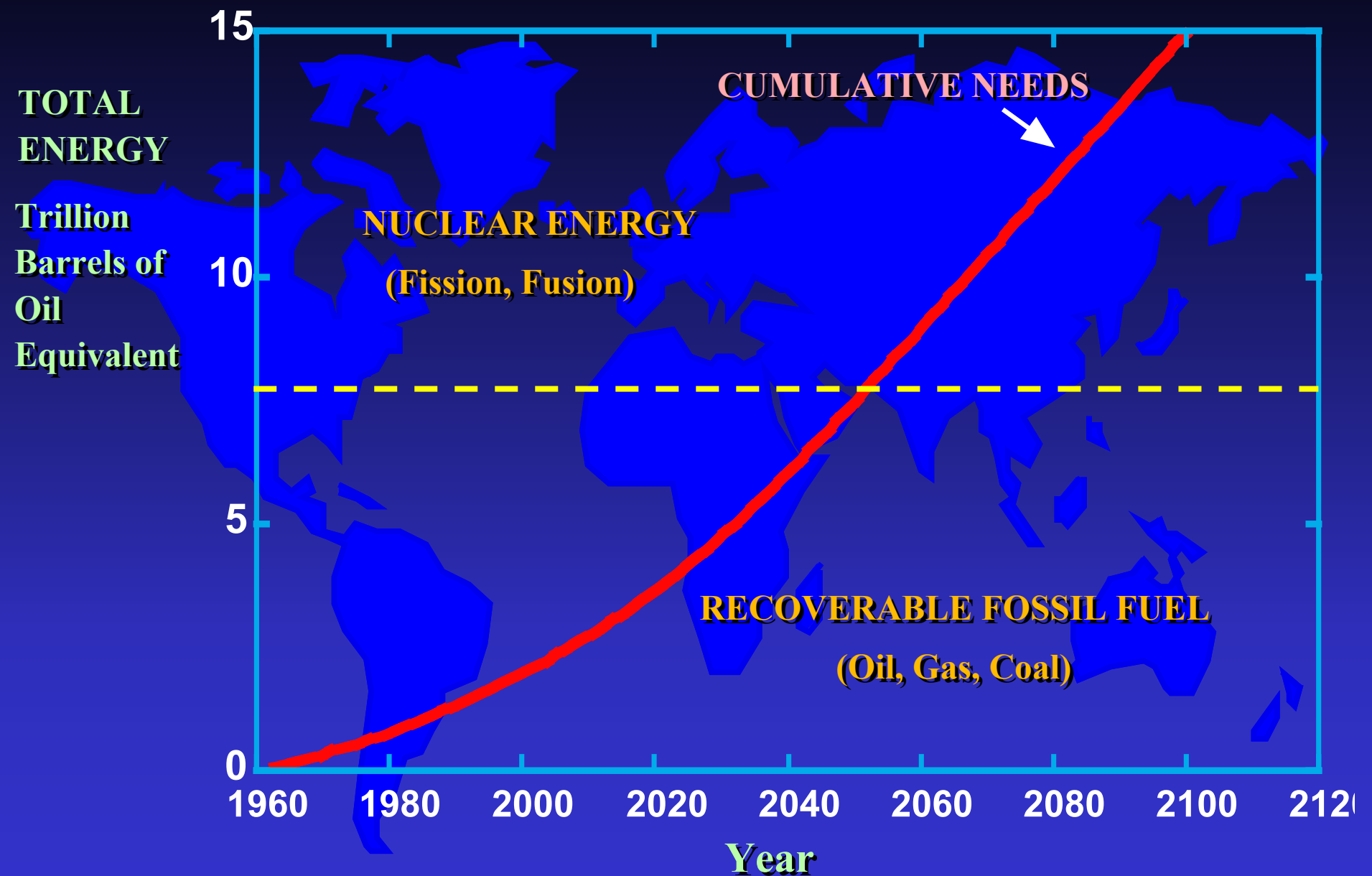
Source: International Energy Annual 2001

**There is Twice as Much Energy in the World's Reserves of Uranium
Used in LMFBR's Than in All the Fossil Fuel Reserves in the World**

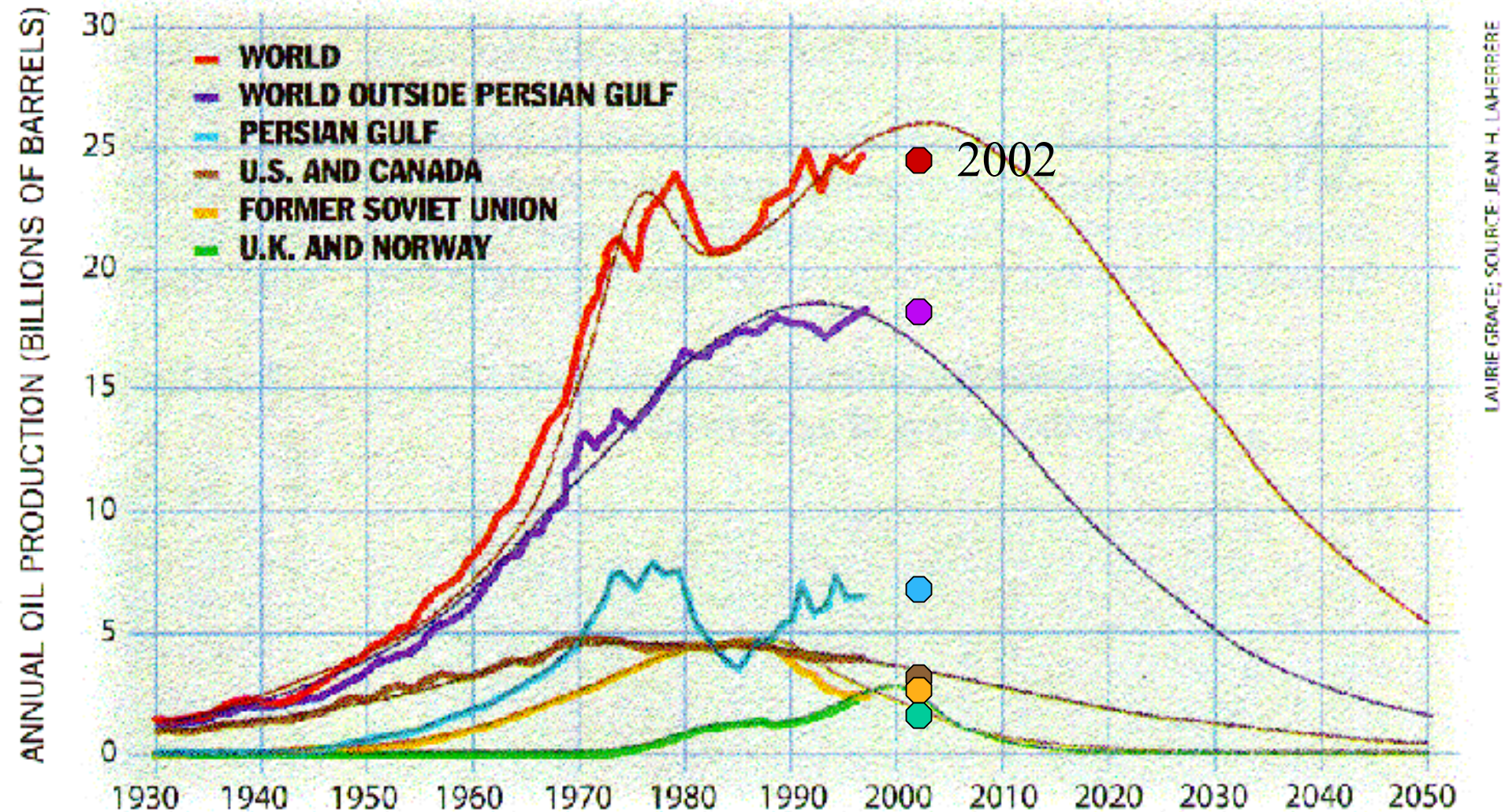


Source: World Nuclear Outlook-1995

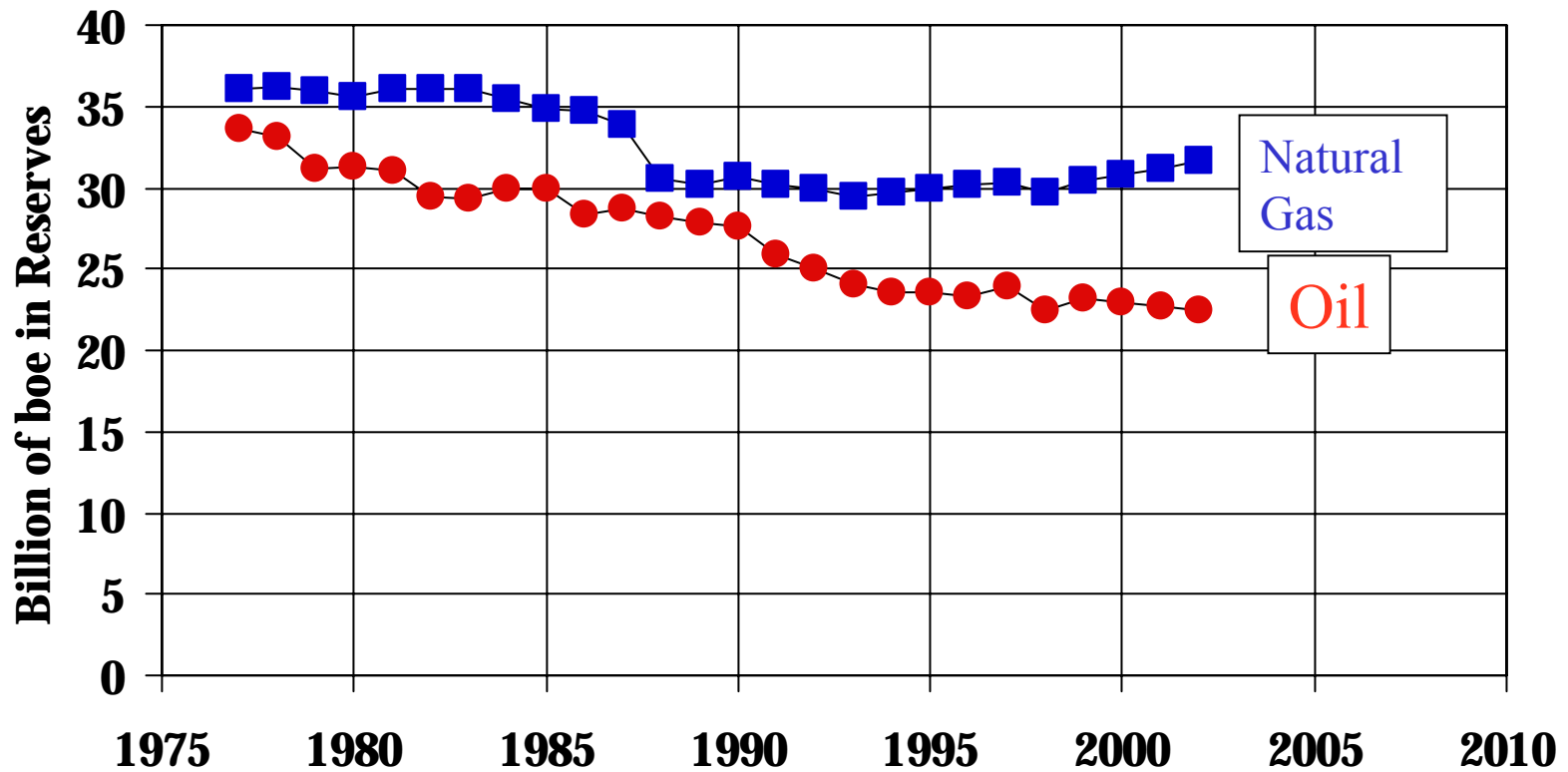
World Energy Consumption and Resources for the Future



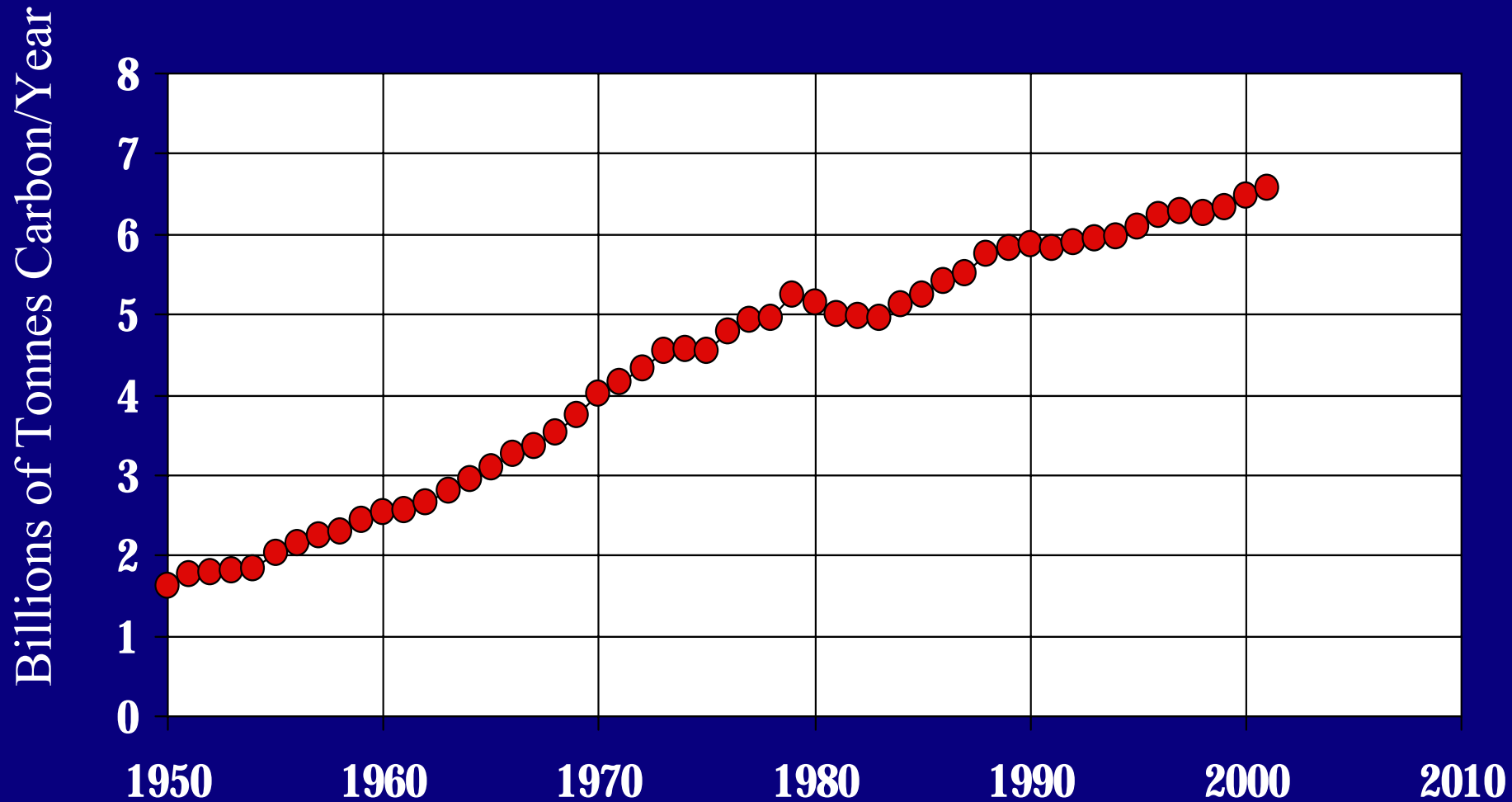
The worldwide production of oil is predicted by Campbell et. al., (**Scientific American, March 1998**) to peak shortly after the turn of the century.



The Proved Reserves of Natural Gas and Oil in the U. S. Have Been Dropping for Over 25 Years



The Worldwide Emissions of Carbon from the Burning of Fossil Fuels is Approximately 1 Tonne per Person per Year



International Energy Annual-2001, DOE/EIA-0219(01), Mar. 2003

Competition for Fossil Energy Can Lead to Conflict



Technical Potential of Solar Energy Used Collected on the Earth

- **1.) Solar energy has the same level of potential to provide essentially inexhaustible long-term energy source for society as does the LMFBR.**
- **2.) Local use of solar energy has the potential to provide only $\approx 5\text{-}10$ billion boe/y while centralized uses have much higher potential.**
- **3.) A global solar option would exhibit enormous heterogeneity.**
- **4.) Land availability is not expected to be a binding constraint in the end.**
- **5.) Large scale storage capacity will probably turn out to be the key barrier**
- **6.) No more than 5-10 billion boe/y should be expected before 2030.**
- **7.) High capital costs are the immediate barrier to commercialization**
- **8.) Environmental effects are not entirely benign (risks in material intensive industries, GaAs, etc.)**

Technical Potential of Renewable Resources

Resource	Annual Energy Potential (billion boe/y)	Comment
Biomass	30	Requires cultivation of virtually all the productive land in the world
Hydro power	15	Includes minor contribution from glaciers
Wind	15	High quality but utilization must deal with energy storage
OTEC	5	Potential is great if ocean heat can be diverted on a large scale
Geothermal	10	Technology not available for large scale heat “mining”. Localized.
Tidal	0.2	Very localized
Total	≈ 75	

What Energy Resources Can We Expect in or From Space ?

- Fossil fuels (coal, oil, natural gas, biomass)?
- Wind?
- Geothermal, Hydro, Waves?
- Uranium?
- Solar?
- What Else?