Nuclear Energy: Beyond 2001

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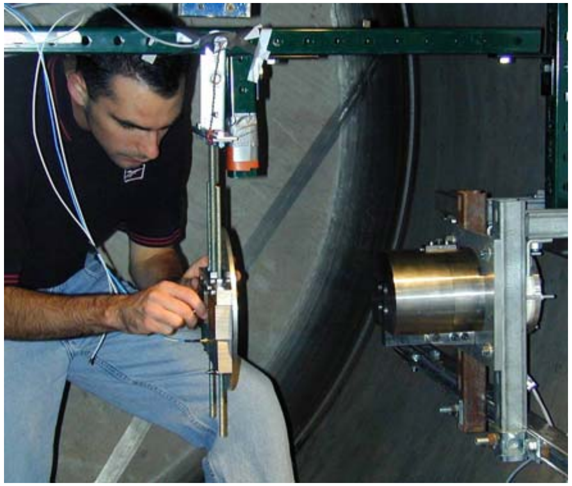
Nuclear Engineering at UC Berkeley

(the only NE program in the UC system)

- UCB Nuclear Engineering Faculty:
  - Professors
    - » William Kastenberg (risk assessment, reactor design)
    - » Donald Olander (nuclear fuels and materials)
    - » Per Peterson (heat transfer, fluid mechanics, inertial fusion)
    - » Stan Prussin (nuclear chemistry, bionuclear engineering)
    - » Ed Morse (fusion)
  - Associate Professors
    - » Jasmina Vujic (neutronics, bionuclear, computational engineering)
    - » Joonhong Ahn (radioactive waste management)
    - » Daniel Kammen (0%, renewable energy technology/energy policy)
  - Professors-in-Residence
    - » Ehud Greenspan (fission and fusion reactor design)

Nuclear Engineering: The boundary conditions

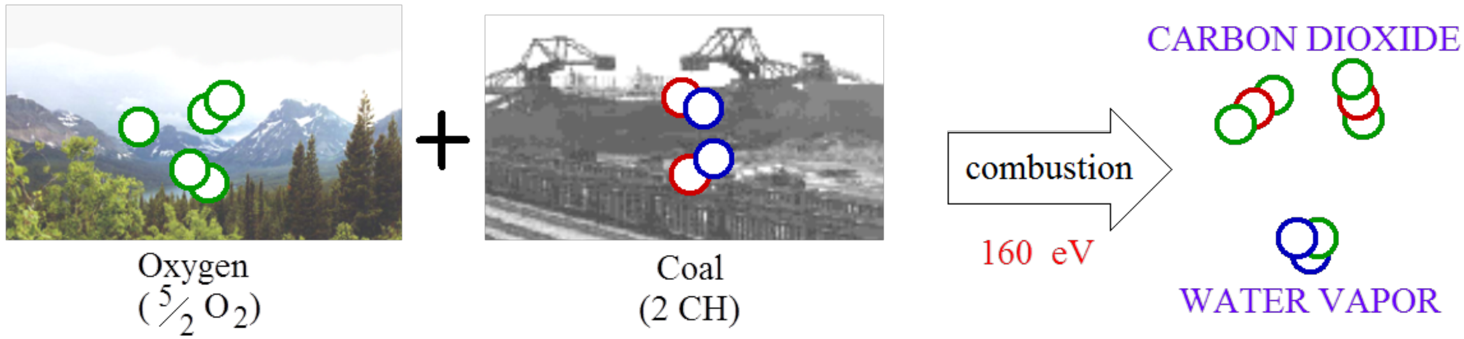
- Yucca Mountain site selection decision this year
- California power crisis
- Generation IV reactor roadmap
- NERI / NEER
- Construction of demonstration Pebble Bed Modular Reactor to start this year
- First fully 3-D NIF capsule simulations
- Peregrine FDA approval



NE Activity: Research/Teching

- NE Graduate Education/Research
  - Radioactive Waste Management
  - Nuclear Energy
    - » Fission
    - » Fusion
  - Nuclear Science and Applications
    - » Bionuclear Engineering
    - » Radiation Physics
- NE Students
  - 25 undergraduate students
  - 40 graduate students
  - Steady decline in number of undergrads over last 8 years

Energy from Fossil Fuels



- **Fossil Fuel (Coal) Energy Density: 2.9 x 10^7 J/kg**
- **Fuel Consumed by 1000-MW_e Plant: 7,300,000 kg/day**
- **Waste:**

Coal Combustion Products		
NO_x	→	High temperature combustion
SO_x	→	Sulfur in coal (0.4% - 5%)
Ash	→	(5% - 25% of coal mass)
CO_2	→	Global warming

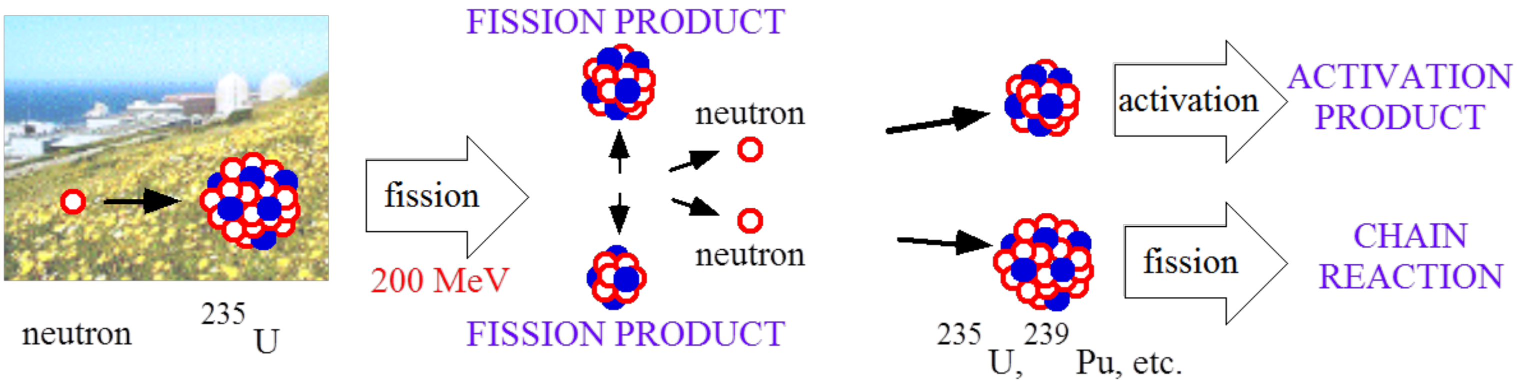
Mining

Leachates/ dust from mining

Construction materials

1999 Global Coal Consumption: 3 billion tons

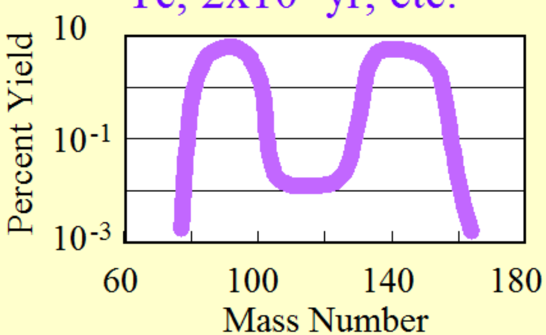
Energy from Nuclear Fission



- **Fission Fuel Energy Density: 8.2 x 10^{13} J/kg (20,000 t_{HE}/kg)**
- **Fuel Consumed by 1000-MW_e Plant: 3.2 kg/day**
- **Waste:**

Fission Prod. (3.2 kg/day)

^{90}Sr, 30 yr; ^{137}Cs, 30 yr; ^{99}Tc, $2x10^5$ yr; etc.



Activation Products

Fuel → Transuranics, longer half lives (^{239}Pu, 24,000 yr; ^{237}Np, $2x10^6$ yr; etc.)

Structures → Moderate half lives, low-level waste (^{60}Co, 5 yr)

Coolants → Low (water) to moderate (metals) half lives

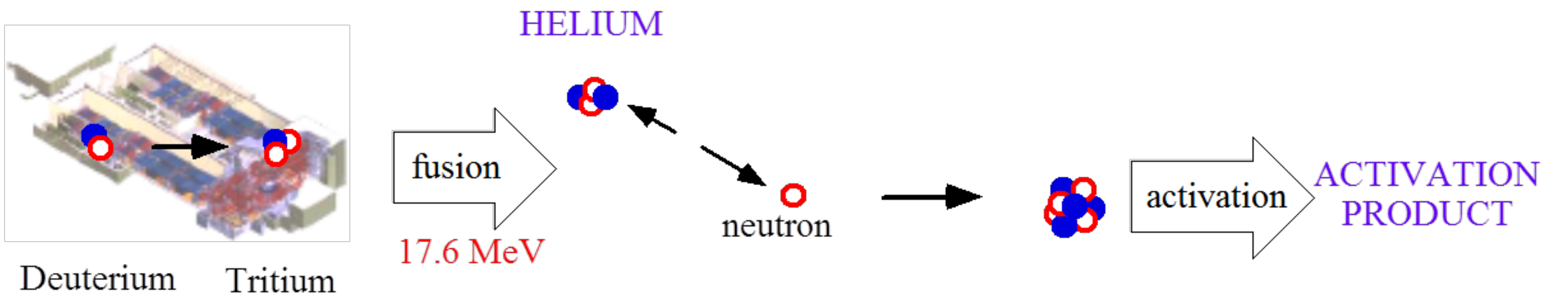
Transmutation → Convert from long to short half life

Mining

Radon from mill tails if not capped

Construction materials

Energy from Nuclear Fusion



- **Fusion Fuel Energy Density: 3.4 x 10^{14} J/kg**
- **Fuel Consumed by 1000-MW_e Plant: 0.6 kg/day**
- **Waste:**

Activation Products

Structures → Moderate half lives, depends strongly on material selection (low atomic mass better)

Coolants → Short half lives (low atomic mass)

Blanket → $n + {}^{6}Li \rightarrow 4He + T$

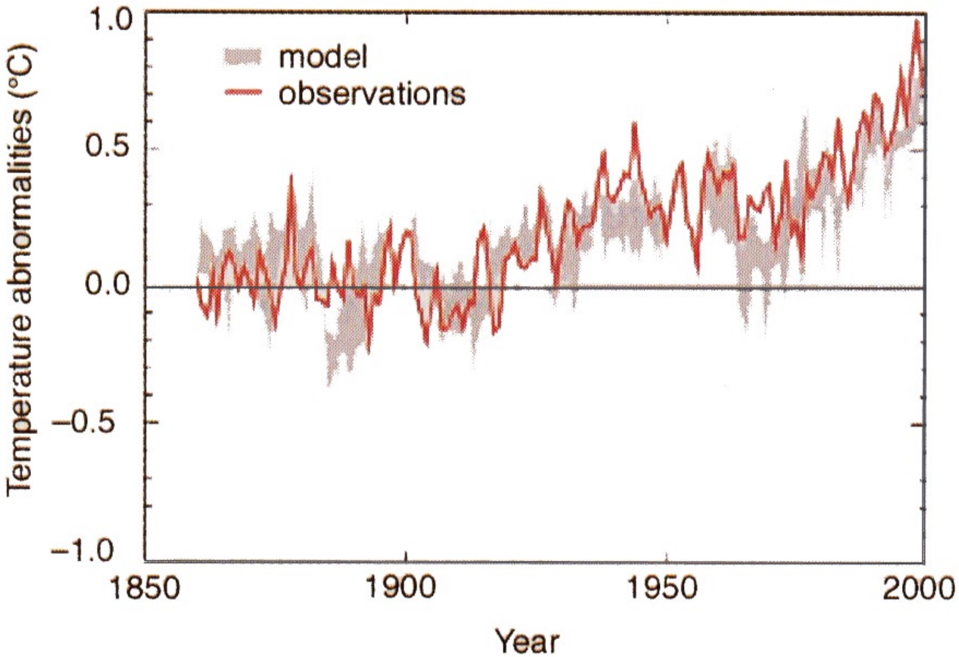
$n + {}^{m}M \rightarrow 2n + {}^{m-1}M$

Mining

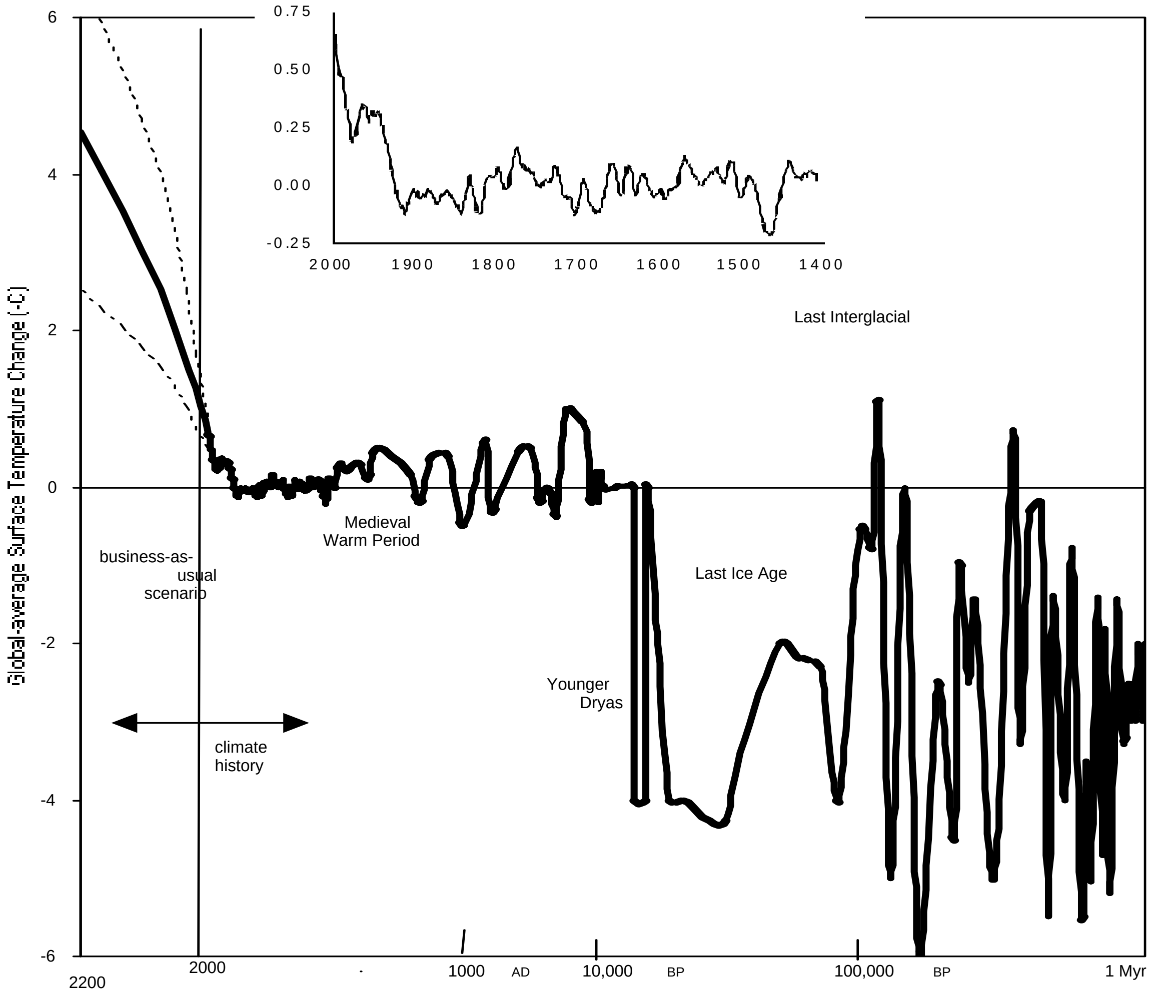
Construction materials

Energy production/use dominates human influence on the environment

- **IPCC January 2001:**
  - **"most of the observed warming over the last 50 years is likely due to the increase in greenhouse gas concentrations."**
  - **temperature increase predicted by 2100: 1.4°C to 5.8°C**
  - **contribution of uncertainty from socioeconomic and from modeling uncertainties are now equal**
- **IPCC 1995:**
  - **"a discernible human influence on global climate"**
  - **temperature increase predicted by 2100: 1.0°C to 3.5°C**

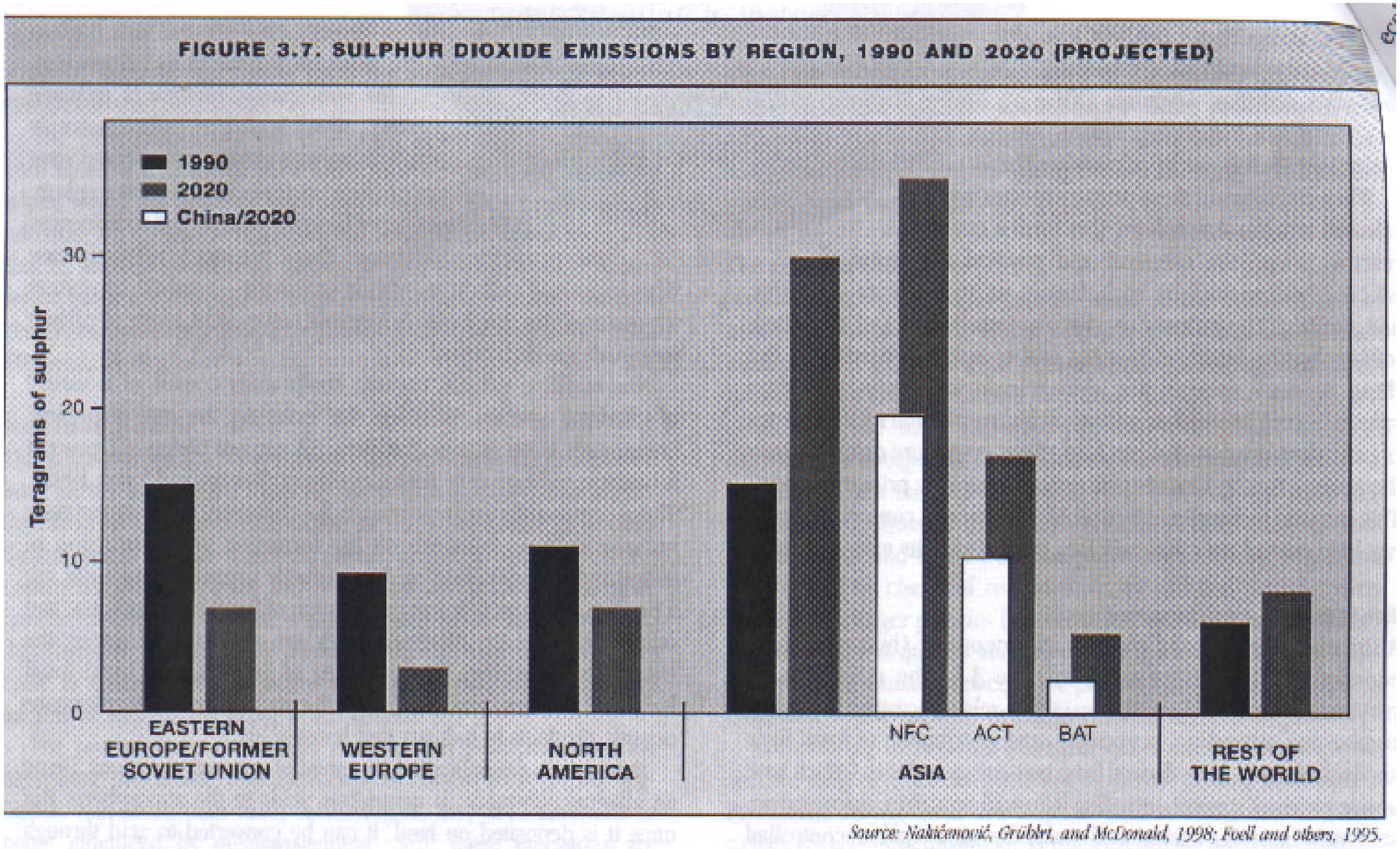


IPCC data compares past/potential future temperatures

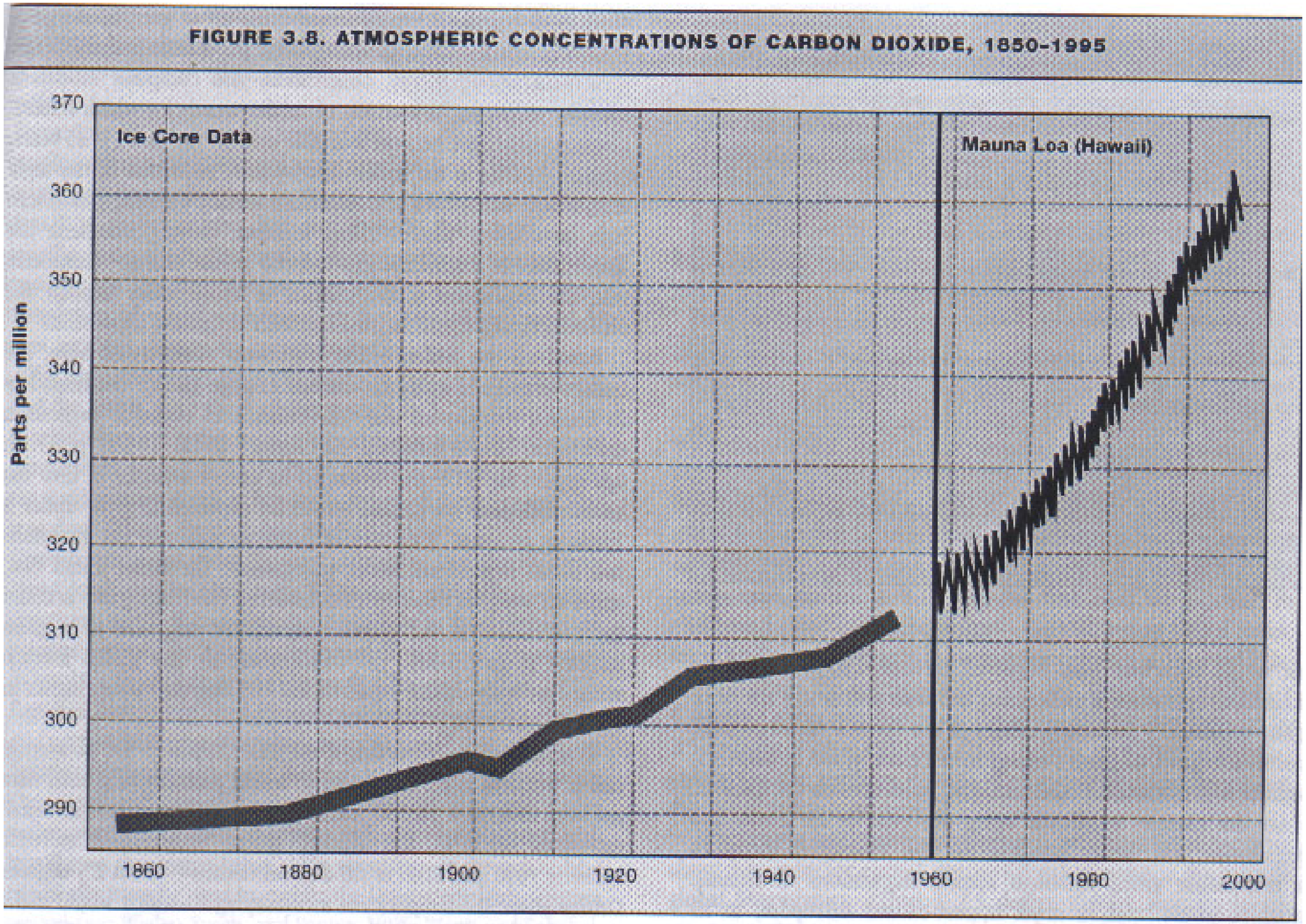


Credit: S. Fetter, 1997

Sulphur Dioxide Emissions by Region, 1990-2020



Atmospheric Concentrations of CO2, 1850-1995



Source: OSTP, 1997.

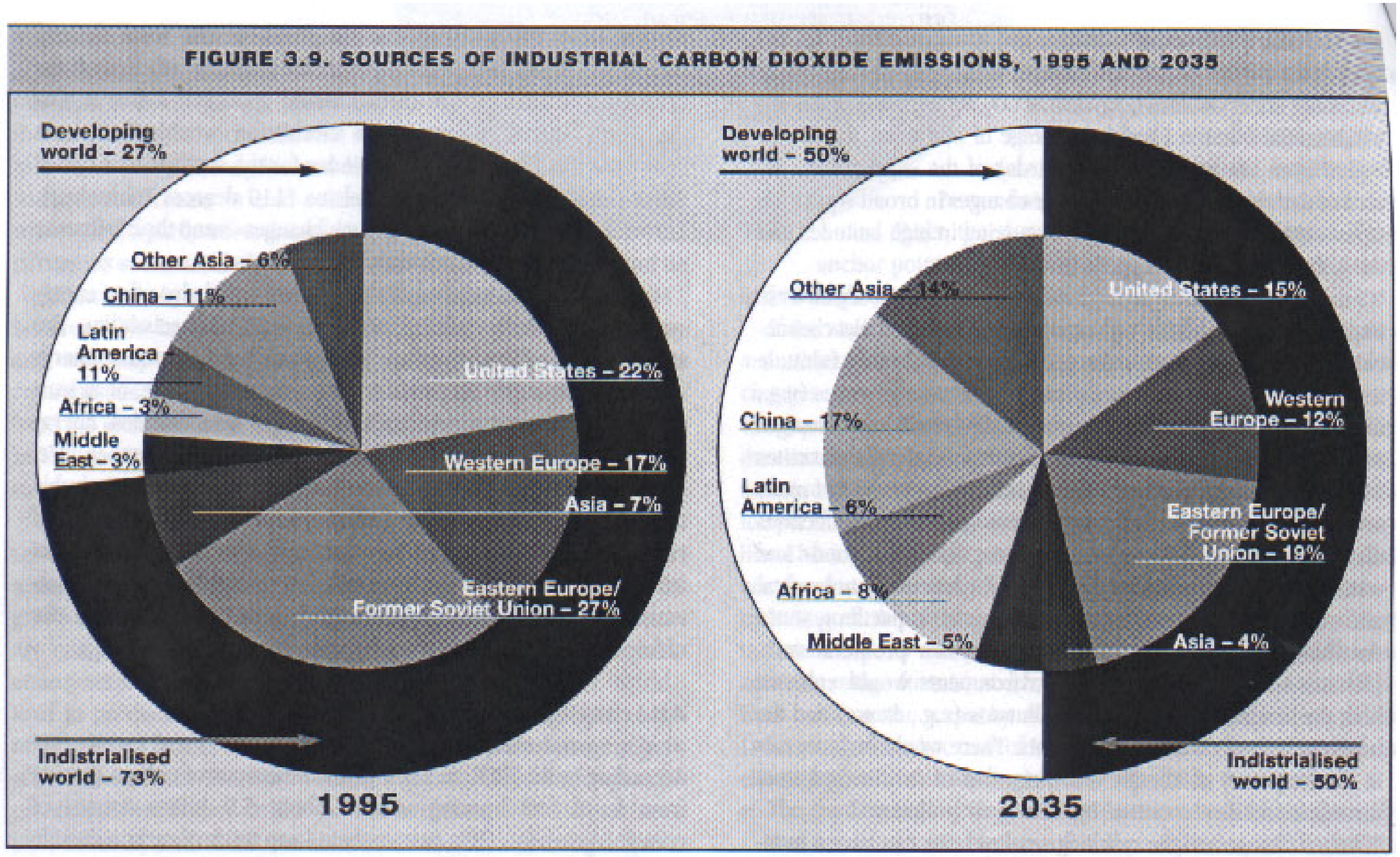
Sources of Industrial Carbon Emissions, 1997

TABLE 3.6 SOURCES OF INDUSTRIAL CARBON EMISSIONS, 1997 (BILLIONS OF TONNES)

Combustion of petroleum products	2.70
Combustion of coal	2.40
Combustion of natural gas for energy use	1.20
Cement manufacturing	0.20
Flaring of natural gas	0.05
Total	**6.60**

Source: Authors' calculations based on energy data from BP, 1998 and USEIA, 1998.

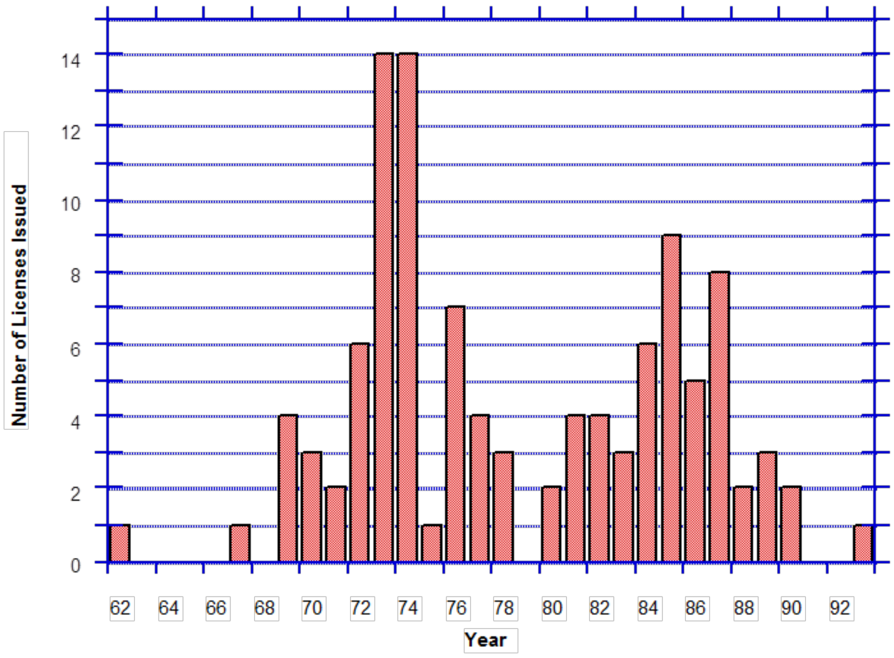
Sources of Industrial CO2 Emissions, 1995-2035



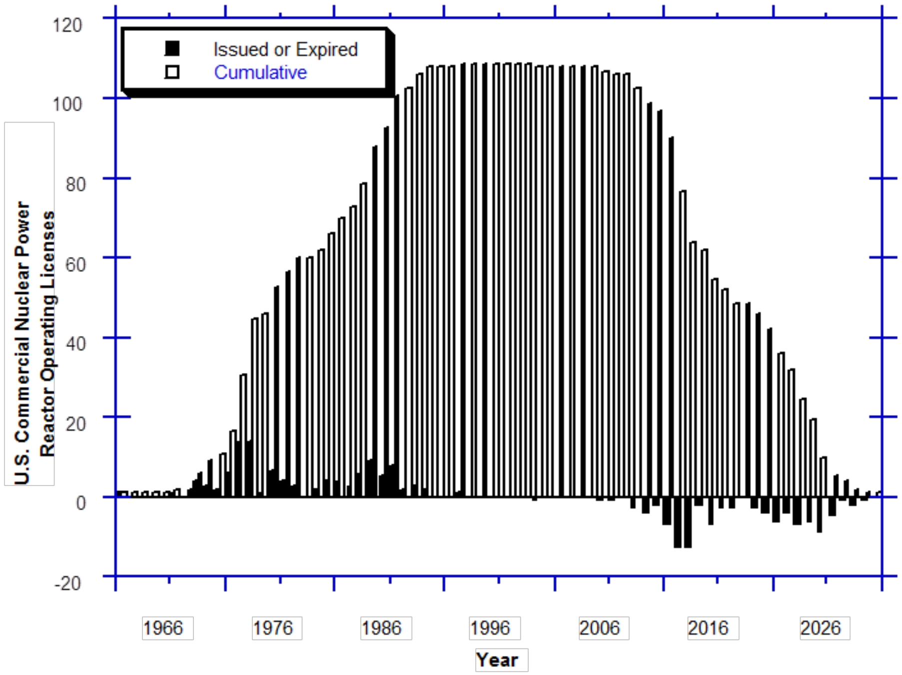
Nuclear Energy: What Went Wrong?

- The Three Mile Island Accident (March 28, 1979).
- The Washington Public Power Supply System (WPPSS) had to abandon construction of 4 out of 5 NPPs in 1980s -the worst bond default in American history.
- The $7-billion WPPSS ("whoops") fiasco effectively killed whatever willingness the financial markets had to fund new nuclear constructions.
- A total of 131 commercial NPPs have been built and licensed.
- 28 of those have been shut down.
- The remaining 103 produce about 20% of the nations' electricity.
- Another 65 plants were cancelled before construction.
- That was more or less the state of things when deregulation of electric utilities began in the middle 1990s.

Number of NPP Licenses Issued in USA



US Commercial NPP Operating Licenses



Nuclear Energy: What Went Wrong?

- The “once-through” fuel cycle policy. To limit the proliferation of nuclear weapons globally, both President Ford and President Carter imposed indefinite bans on commercial reprocessing in the US.

- Unresolved issue of the permanent disposal of high-level radioactive waste. Although obligated by the Nuclear Waste Policy Act of 1982 and its Amendments of 1987 to begin accepting spent fuel from commercial nuclear power plants by January 31, 1998, if no repository is completed or operated by then, the U.S. Department of Energy (DOE) has not yet built or sited a permanent disposal facility.

- Since 1987, the siting investigations have been directed to one site only - Yucca Mountain, Nevada, but the final decision has not been made. The current situation, with spent fuel residing in spent fuel pools or in dry cask storage on-site, may become intolerable, from a public acceptance point of view.

Nuclear Energy: What Went Wrong?

- Overregulation and luck of standardization. The nuclear power generation in the U.S. become so overregulated that this itself prolonged the construction of power plants. Also, non-existence of centralized planning, many delays and changes in regulations during the construction had a consequence of producing almost every NPPs with a unique design, thus increasing construction time and cost considerably. This scheme became known as “custom designs - custom regulatory reviews”.

- Proliferation issues. These issues are related to the use and design of nuclear power reactors in developing countries, and the conversion of excess weapons plutonium to MOX fuel for use in LWRs.

- Decommissioning. Initially commercial reactors are licensed to operate for 40 years, and can renew their licences for an additional 20 years.

Nuclear Energy:What Went Wrong?

- Deregulation of the electric utility industry. In 1992, the U.S. Congress passed the National Energy Policy Act, effectively allowing the electric power industry deregulation (i.e., competition in electricity sales), and putting intense pressure on the nuclear industry to become more competitive.
- This pressure led to the requests of more efficient electricity generations at NPPs through restructuring, downsizing, moving to a two-year fuel cycle, reducing the outage length, and increasing the capacity factor in order to reduce the operations and maintenance costs, and thus lower the cost per kWh of nuclear-generated electricity.
- In California, the State Legislature has instituted a 5 year transition period to a full competitive market by the year 2002.

Asia - Pacific Region

- On the threshold of the 21st century the world is facing considerable energy and environmental challenges. It is well know that there is a direct link between access to electricity and energy supplies, and quality of life in terms of availability of food, housing, medical treatment, and/or education.
- Underdeveloped and developing countries use fossil fuels as the major source of energy today, and will continue using it as the major energy source in the future. For example, China with its population of 1.2 billion is becoming the single largest source of energy demands for the next two decades. China already burns over a billion tons of coal per year.[1]
- While the United States (as well as most European countries and Canada) halted construction of new nuclear power plants and considerably reduced research and development in this field in the last two decades, nuclear energy capacity has steadily increased in far-eastern Asian countries such as Japan, South Korea, and Taiwan. Large-scale nuclear development has also started in China and other Pacific region countries.

Asia - Pacific Region

Table 1: Anticipated Nuclear Power Capacity (MWe), 1998-2010

Country	1998	2000	20005	2008	2010
Japan	**45,362**	**45,362**	**46,022**	**52,230**	**54,680**
S. Korea	**12,016**	**13,716**	**17,716**	**20,716**	**22,716**
China	**2,100**	**2,100**	**7,670**	**10,670**	**11,670**
Taiwan	**5,148**	**5,148**	**5,148**	**7,848**	**7,848**
India	**1,858**	**1,758**	**2,678**	**3,273**	**3,773**
Pakistan	**137**	**437**	**437**	**437**	**437**
Indonesia	**0**	**0**	**0**	**0**	**0**
N. Korea	**0**	**0**	**1,000**	**2,000**	**2,000**
Bangladesh	**0**	**0**	**0**	**0**	**0**
Total	66,621	68,523	80,534	97,589	103,539

JAPAN

- In Japan, as of March 1998, 53 nuclear power plants were under operation with capacity of 45.2 GWe, accounting for one third of all electricity generated in Japan.[15] Recently, and advanced BWR (ABWR) unit with capacity of 1,365 MWe was constructed for less that 5 years with the reduction of construction cost by 20-30% as compared with the conventional 1,100 MWe BWRs. The current and the future (planned) energy supply in Japan is shown in Table II[15]:

Table 2: Japanese Energy Supply[15]

Primary En. S	1994 [GW]	2010 [GW]	2030 [GW]
Coal	90	100	60
Oil	330	310	310
Natural Gas	60	90	110
Hydro	20	30	30
New energy	10	20	80
Nuclear	70 (40.6 GWe)	110 (70.5 GWe)	160 (100 GWe)
Total	580	660	750

South Korea

- South Korea has the most stable situation in nuclear power production and operation. The electricity demand annually has increased steadily for about 11% over the last several years.[12] About 35% of total electricity is generated by nuclear power (Table III[12]).

- At present, S. Korea has 12 nuclear power reactors (10 PWRs and 2 CANDU) and 6 units under construction (4 PWRs and 2 CANDU). KSNP, Korean Standard Nuclear Power Plant, is a product of research and development of S. Korean research organizations and industry.

- It seems that S. Korea has adopted the French model of standardized designs that reduced the construction time, simplified the regulations, training, and improved safety feature.

South Korea

Table 3: Primary Energy Supplies in S. Korea[12]

	Hydro	Coal	Oil	Gas	Nuclear
Generating Capacity, MW (%)	3,094 (8.7)	7,820 (21.9)	6,535 (18.3	8,636 (24.2)	9,616 (26.9)
Power Gener- ation, GWh (%)	4,210 (2.1)	54,610 (27.3)	37,930 (18.9)	32,930 (16.5)	70,440 (35.2)

CHINA

- **Recent studies[1] have conculded that China will be a driving force in the world's energy demand in the near future. China's GDP has been growing at an average rate of 9.5% for the last 15 years, and will continue to grow at rate of 7-8% each year until year 2015.**
- **Domestic energy supply is almost entirely coal, causing large environmental pollution. China's carbon emissions from coal, oil, and natural gas burning power plants are expected to be the world's highest by 2015, according to the U.S. Department of Energy analysis.**
- **For example, in 1995, coal accounted for 74.5% of China's energy mix, and is expected to increase to 77.4% by 2015. Based on the 1994 data[10], oil accounted for less than 20%, hydro power for about 5%, natural gas for 2% and nuclear power for less than 1%.**

CHINA

- **Under the Five Year Plan (1996-2000)[1], China was trying to increase electricity generation for about 17 GWe per year, largely by coal burning. The total installed capacity is planned to reach 300 GW by 2000 and 800 GW by 2020.[10]**
- **However, China's energy resources are mostly located in northern and northwestern provincies, while the most of its economic growth is along the southern and eastern coast. Existing rail capacity is insufficient to transport large volumes of coal. Similar situation is with China's oil and natural gas resources.**
- **In 1995 construction began on the Yangtze river dam, a part of the Three Gorges Project that will lead to the world's largest hydro power system (twenty six 500 MW turbines). Even if China fully utilizes its hydro resources, the hydropower could contribute to less than one third of the projected capacity for 2015.**

CHINA

- Having above analysis in mind, China is seriously looking into the nuclear option.
- By some predictions[16] China's nuclear energy is projected to grow faster than in any other country. In 1995, nuclear capacity accounted fo only 0.4 %.
- Current plan targets the total nuclear power capacity of 20 GWe to be constructed and put in operation by 2010, that will account for about 4.5 % of power generation in China.
- Based on the existing and planned NPPs (each site has been of a different reactor design), China might be expected to face problems similar to those that occured in the United States: increased cost due to non-standardized designs, increased regulation, increased cost of training, operations, and maintenance.

CHINA

Table 5: Nuclear Power Reactors in China (Up to Year 2004)[10]

Reactor Number	Plant Location	Capacity (MWe)	Type	Commercial Start
6	Qinshan 2a	680	PWR (China)	2001
7	Qinshan 2b	680	PWR (China)	2001
8	Qinshan 3a	728	CANDU-7 (Ca)	N/A
9	Qinshan 3a	728	CANDU-7 (Ca)	N/A
10	Daya Bay 2a	984	PWR (Fra)	2003
11	Daya Bay 2a	984	PWR (Fra)	2003
12	Lianyungang 1	1000	VVER (Russ)	N/A
13	Lianyungang 2	1000	VVER (Russ)	N/A
14	Daqinq	200	Heating reactor (china)	2000