The Future of Nuclear Power

The 1950s

“Too cheap to meter...”

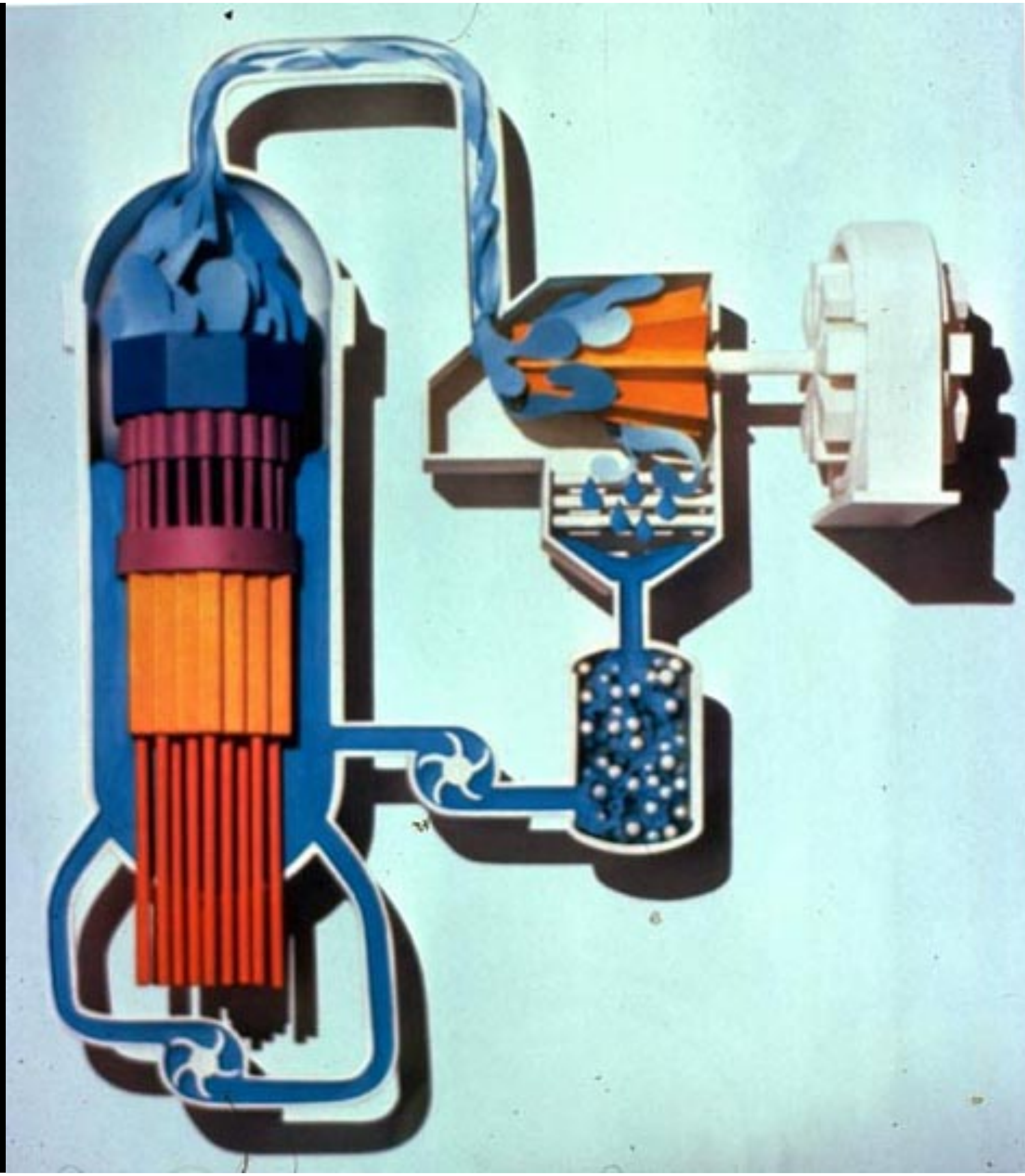
"It is not much to expect that our children will enjoy in their homes electrical energy too cheap to meter, will know of great periodic famines in the world only as matters of history, will travel effortlessly over the seas and under them and through the air, and will experience a life span far longer than ours. This is th forecast for an age of peace.”

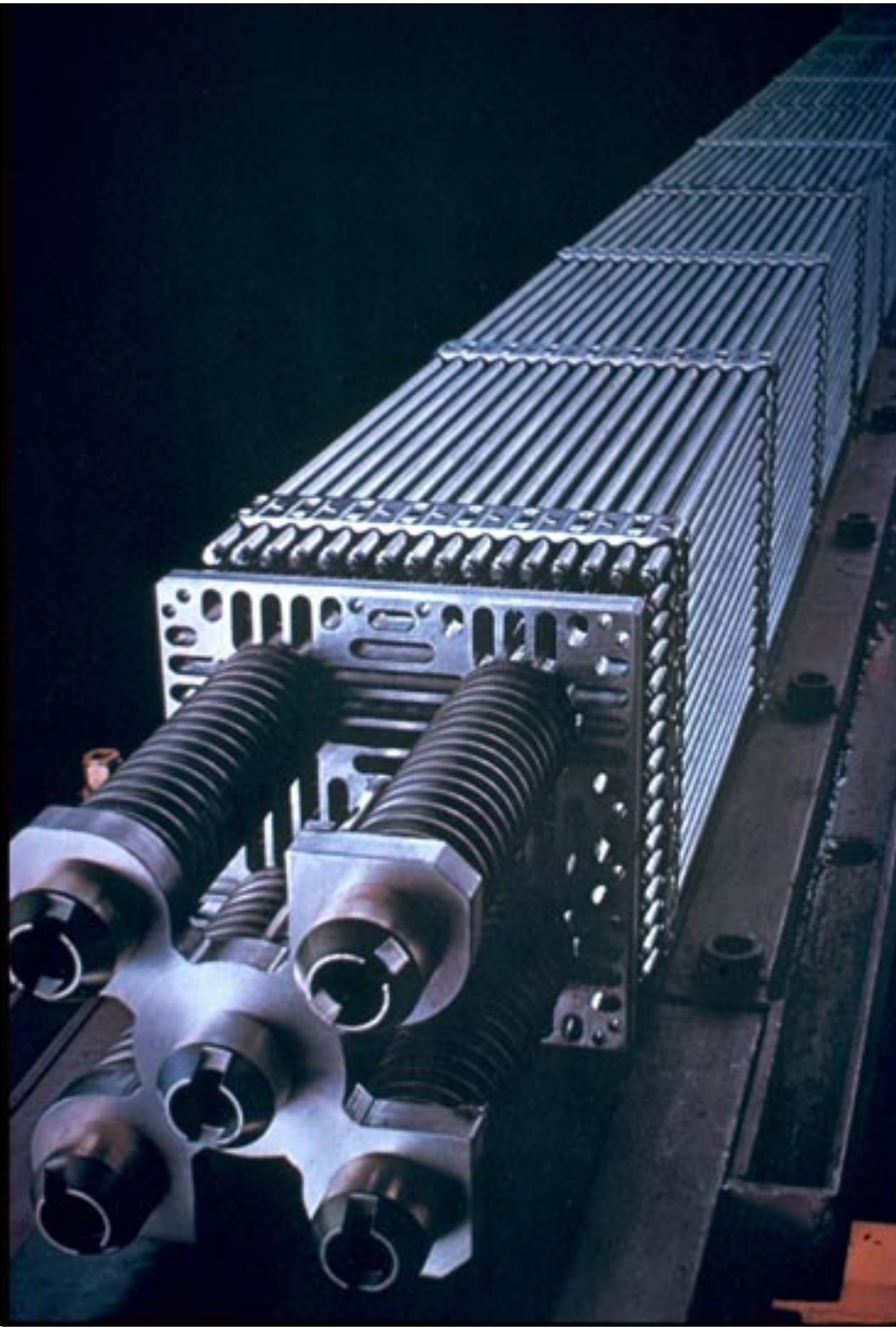
Lewis Strauss, Chairman, AEC

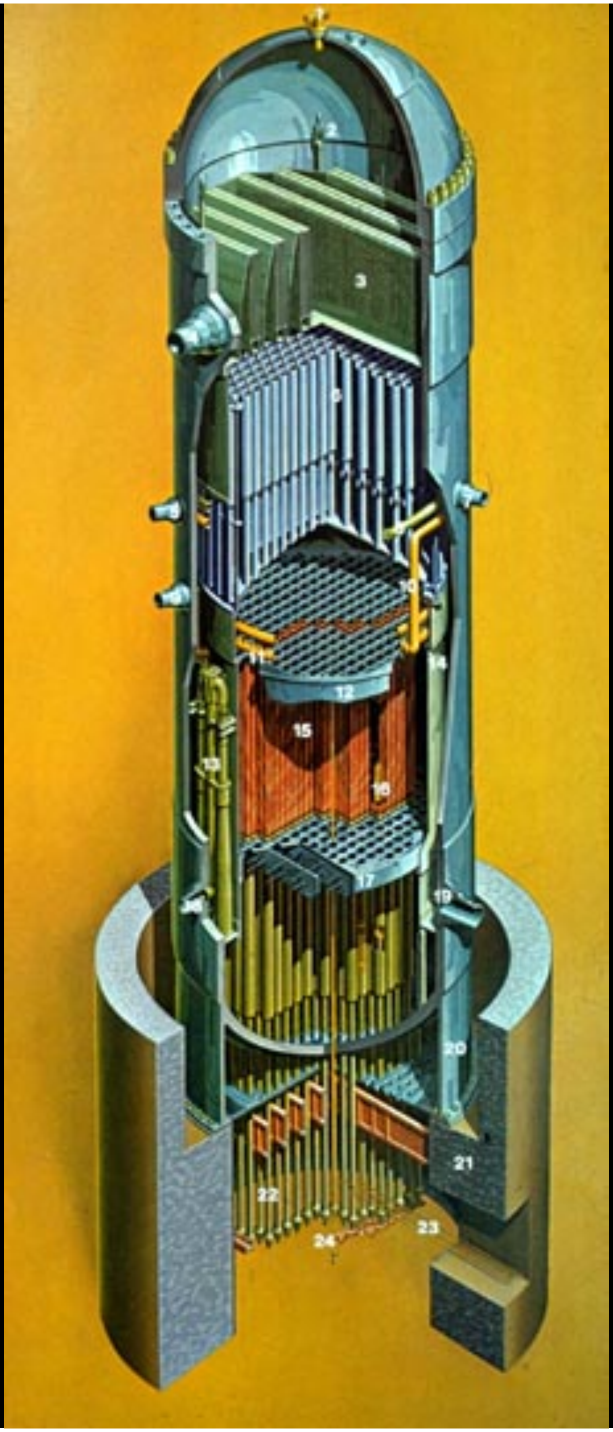
The 1960s

- Oyster Creek – "turnkey contracts"
- General Electric vs. Westinghouse
- 48 plants ordered in 1966-67
- 200 plants operating, under construction, or on order by 1974

A Primer on Nuclear Power







REACTOR BUILDING

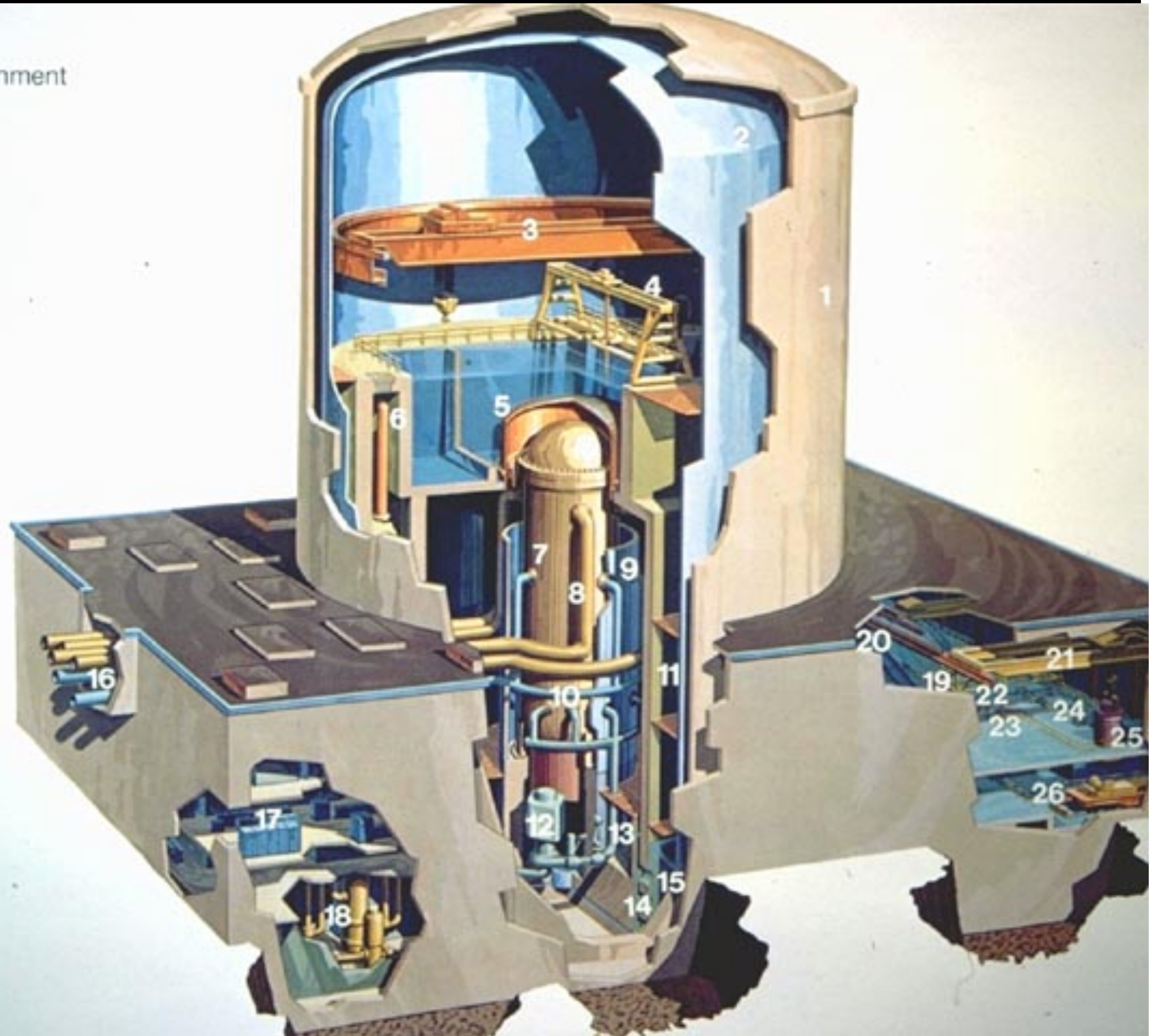
1. Shield Building
2. Free-Standing Steel Containment
3. Polar Crane
4. Refueling Platform
5. Upper Pool
6. Reactor Water Cleanup
7. Reactor Vessel
8. Steam Line
9. Shield Wall
10. Feedwater Line
11. Drywell
12. Recirculation Loop
13. Weir Wall
14. Horizontal Vent
15. Suppression Pool

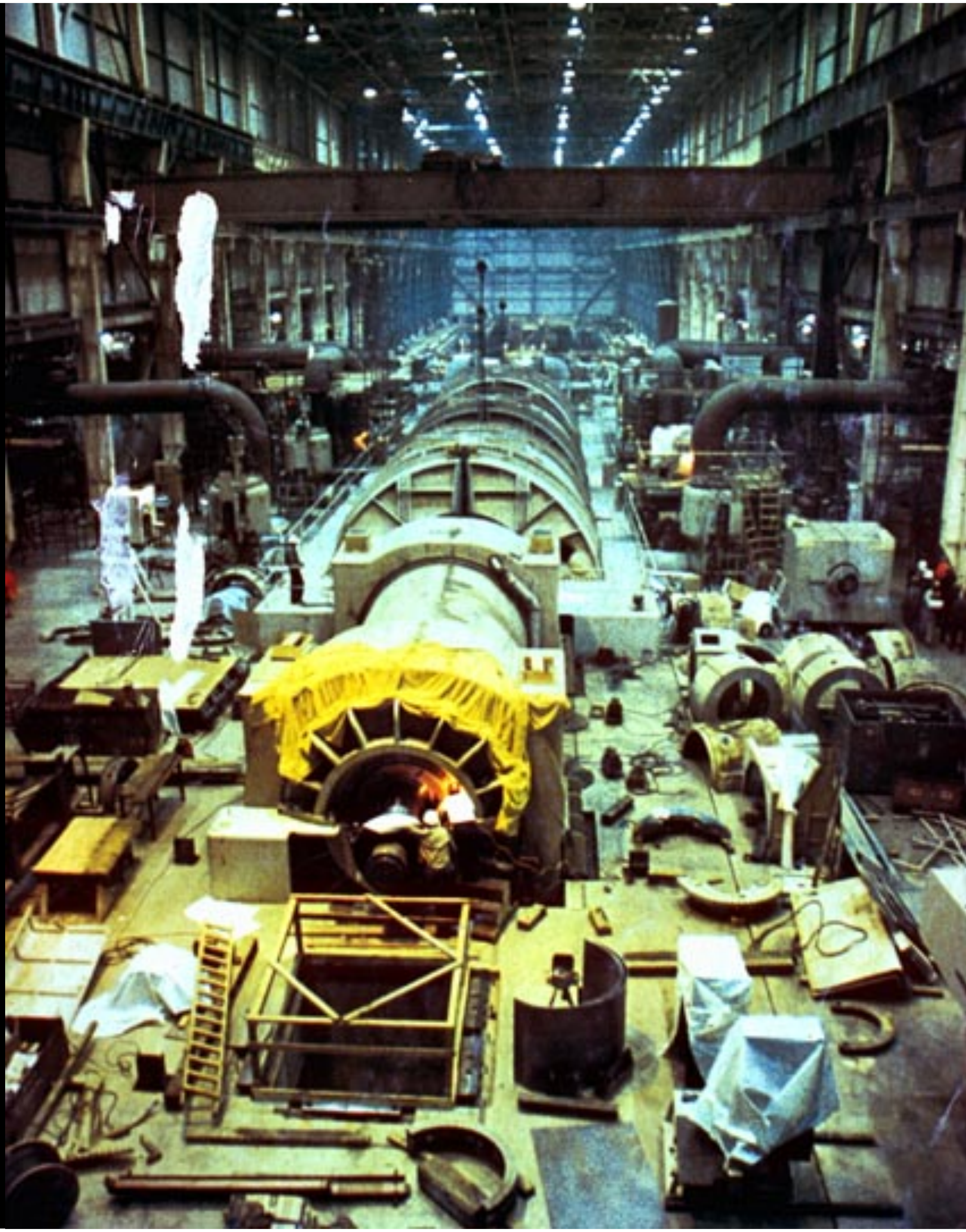
AUXILIARY BUILDING

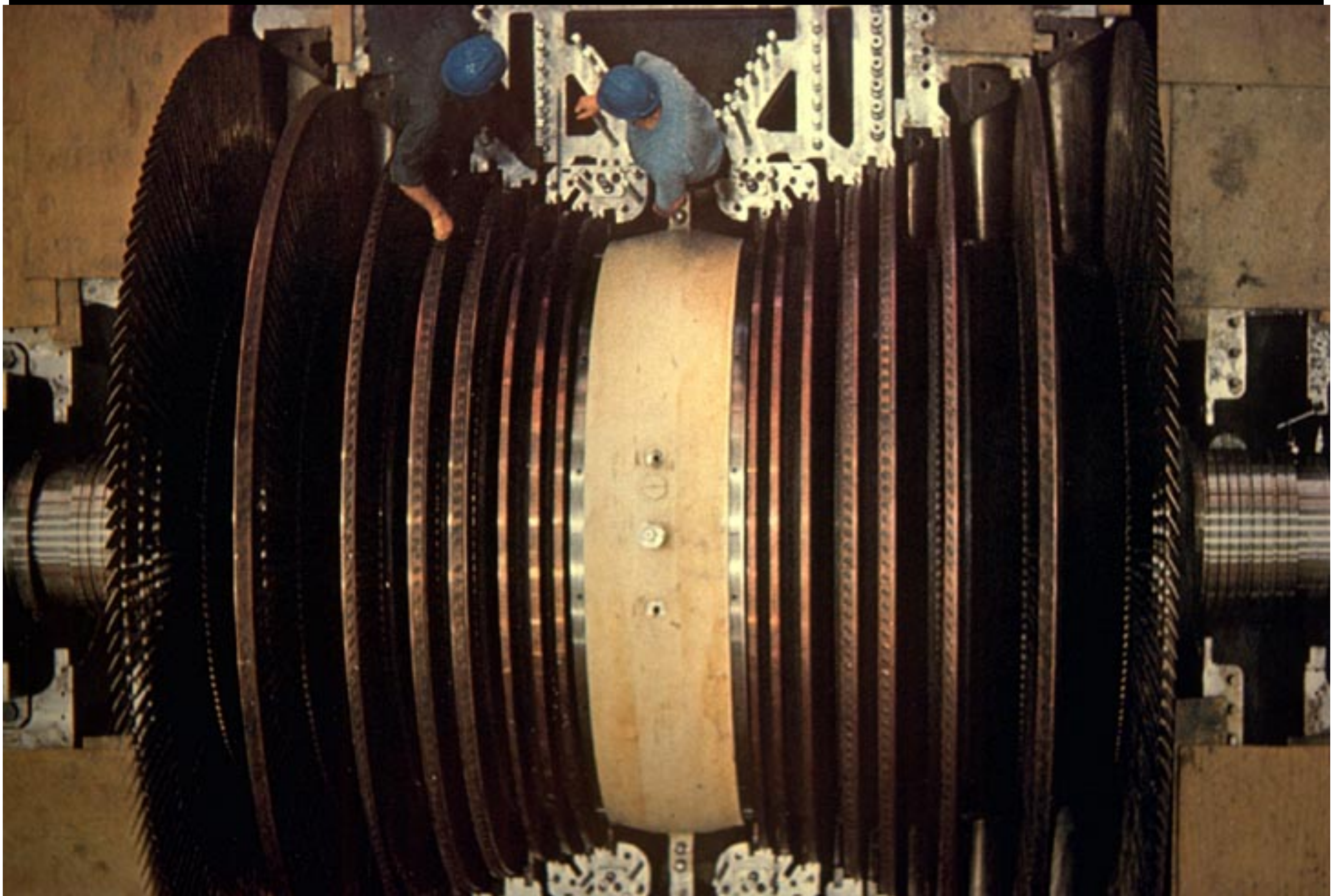
16. Steam Line Tunnel
17. Motor Control Centers
18. RHR System

FUEL BUILDING

19. Fuel Transfer Bridge
20. Fuel Transfer Tube
21. Cask Handling Crane
22. Fuel Storage Pool
23. New Fuel Vault
24. Cask Loading Pool
25. Spent Fuel Shipping Cask
26. Fuel Cask Skid








UNNECESSARY PERSONNEL
STAY BEHIND LINES

"Nuclear Power and You"

The 1970s

- OPEC oil embargo (crude oil > $40/bbl)
- Great concern about future energy sources
- Projections: 1,000 nuclear plants in U.S. by 2000
- Major investment in nuclear power

The Bottom Drops Out

- In 1979 Three Mile Island focused public concern on the safety of nuclear power plants.
- Double-digit interest rates pushed capital-intensive nuclear plant costs through the ceiling (x 10!).
- Increasing regulatory challenges and delaying tactics brought licensing to a halt.
- The Arab oil embargo and increased energy prices stimulated energy conservation leading to over capacity.
- All 103 plants operating today were ordered before 1975.

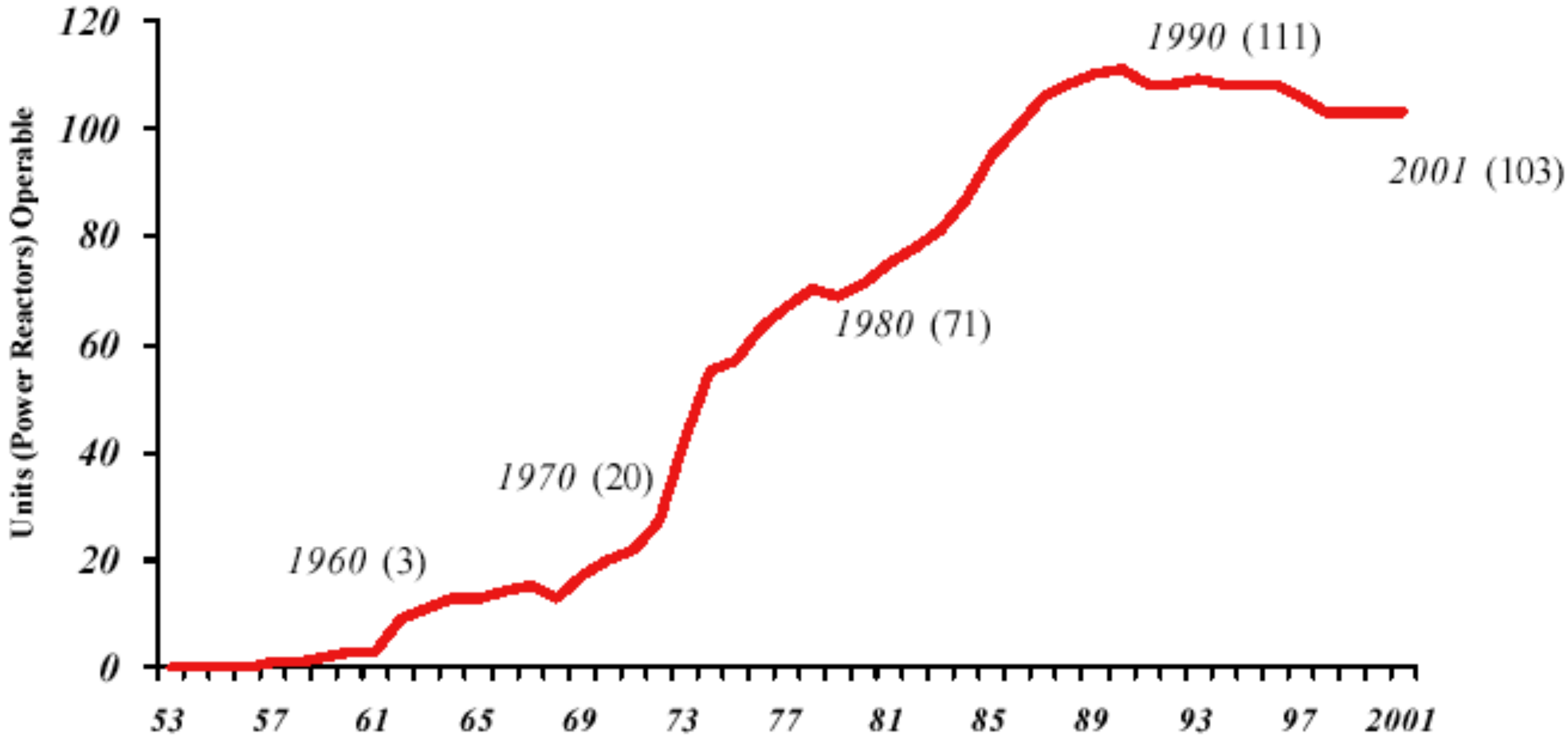
The 1980s

- High costs of nuclear plants were effectively subsidized by regulatory environment.
- Deregulation allowed for recovery of "stranded costs".
- Once capital costs were written down, nuclear plants could compete with fossil fuels on basis of operating costs.

U.S. Nuclear Power Plants

103 Nuclear plants with operating licenses

Operable U.S. Nuclear Power Plants (Units) (1953-2001)

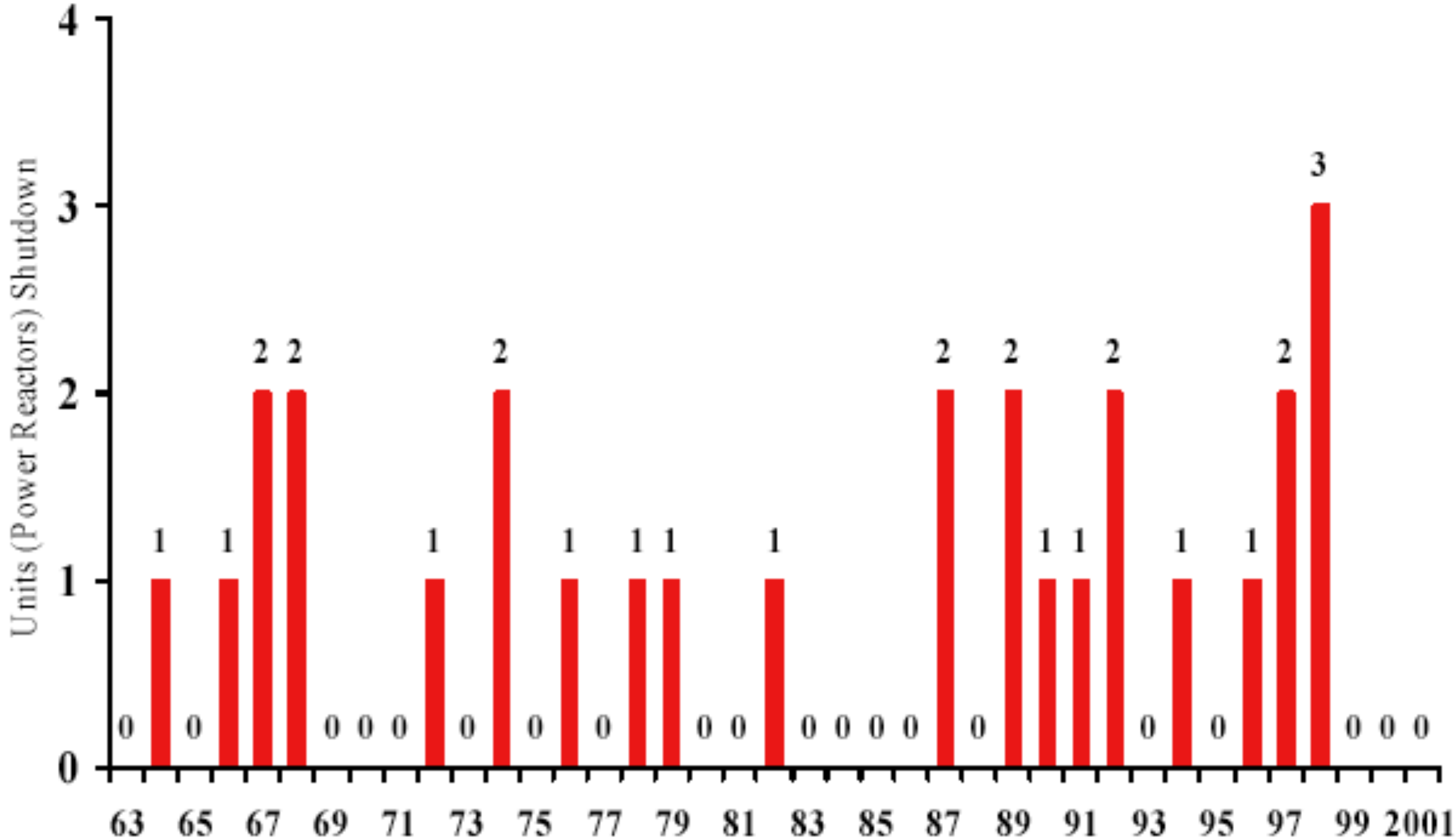


Total of units holding full-power licenses, or equivalent permission to operate, at the end of the year.

Source: EIA

NEI

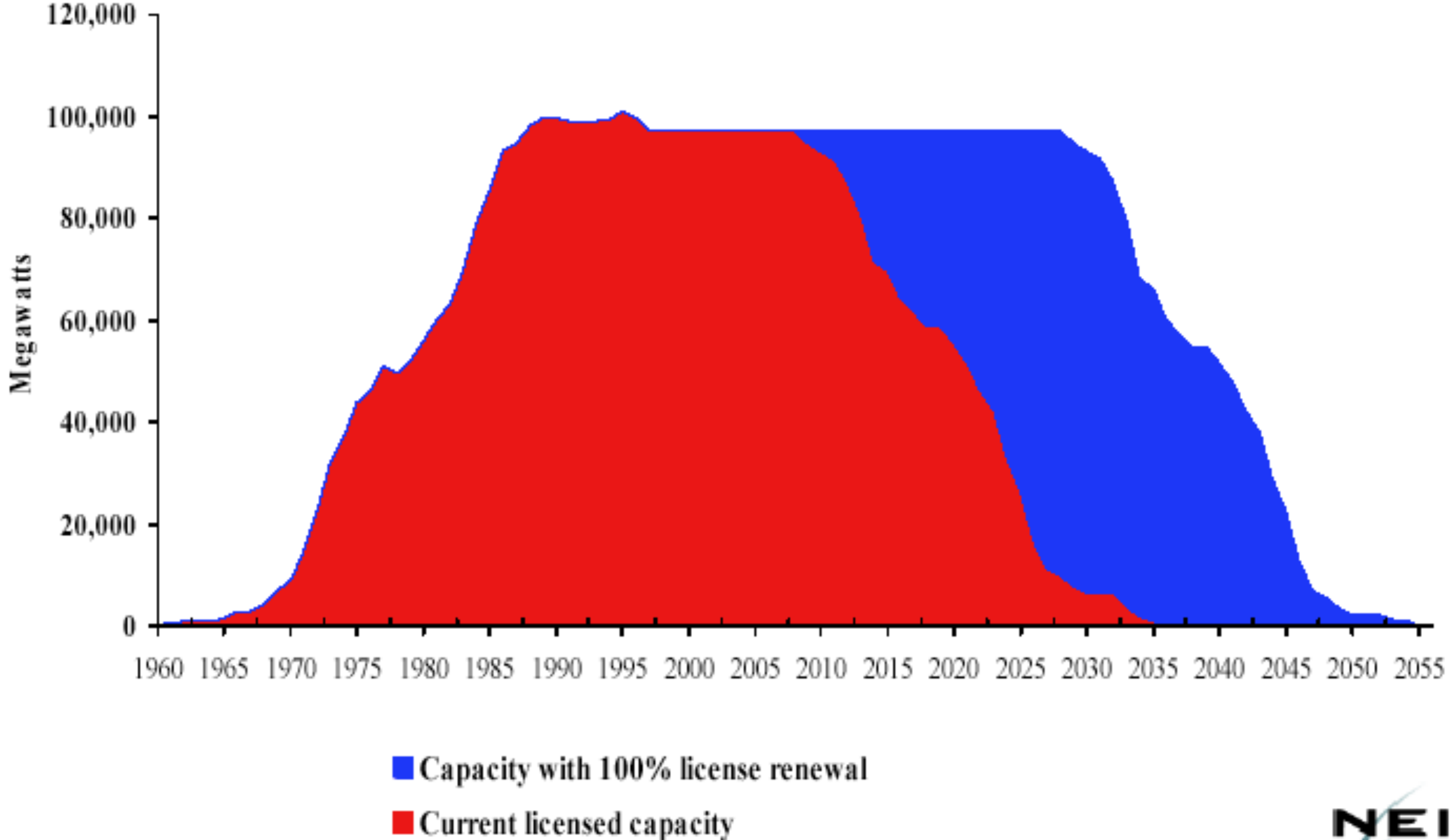
U.S. Nuclear Power Plant Shutdowns



"Shutdown" = removed permanently from service

Source: EIA

U.S. Nuclear Generating Capacity With and Without License Renewal



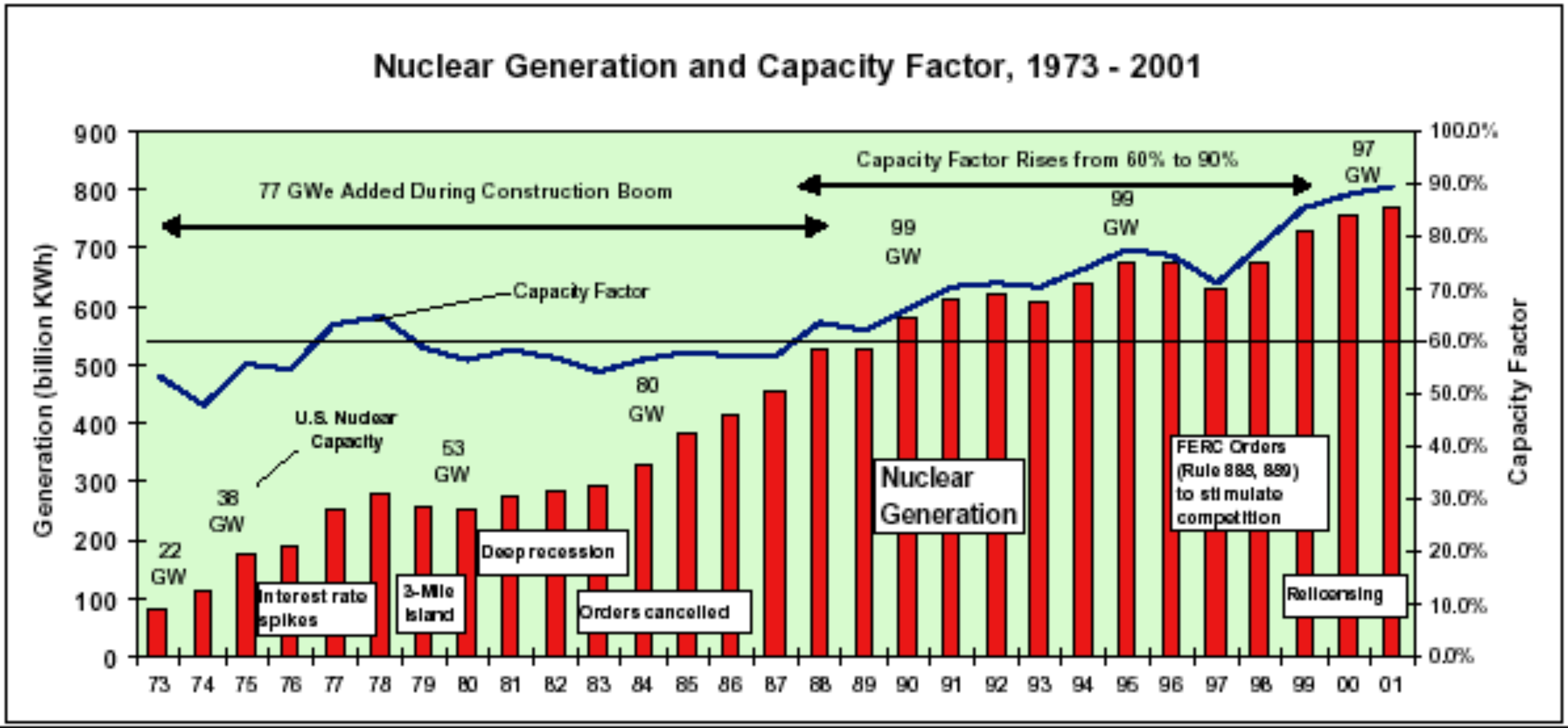
NEI

The 1990s

- Recovery of stranded costs
- Improvement in capacity factors (60% to 90%)
- Consolidation of nuclear plant operators
- By 1999, nuclear plant operating costs had dropped below those of coal-fired plants (2 cents per kwh)

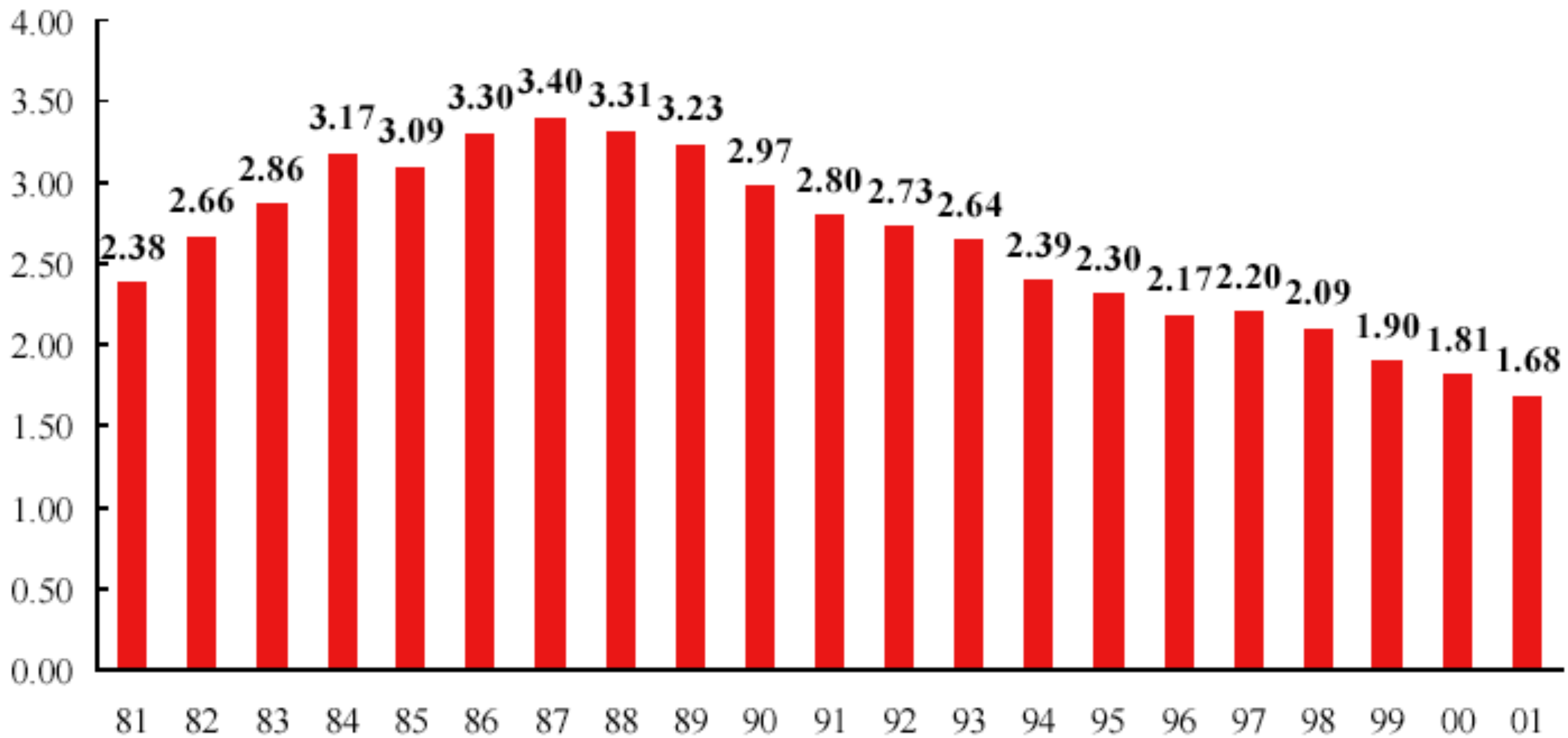
U.S. Nuclear Power Generated, Capacity Factor Improved, 1973 – 2001

- Nuclear power produced in 2001: 768 billion KWh (up from less than 100 billion KWh in 1973, driven by the addition of 77 GWe of capacity between 1973 and 1987). U.S. nuclear plants operate as baseload units.
- Commercial orders were cancelled in the early 1980s, in part due to high interest rates, the TMI accident, and recession. Some units were finished in the mid-1980s, but no net capacity was added after 1989.
- U.S. fleet-wide capacity factor: Rose from 60% in 1987 to over 90% in 2001 due to advances in management systems and practices and much shorter fuel outages. Upratings could add another 7 GWe before 2010.
- Because the U.S. nuclear fleet is now approaching a real capacity-factor ceiling, future increases in KWh generated will be limited unless new reactors are built.



Average U.S. Nuclear Industry Production Costs (O&M + Fuel) (1981-2001)

(in cents per kilowatt-hour: 2001 dollars)

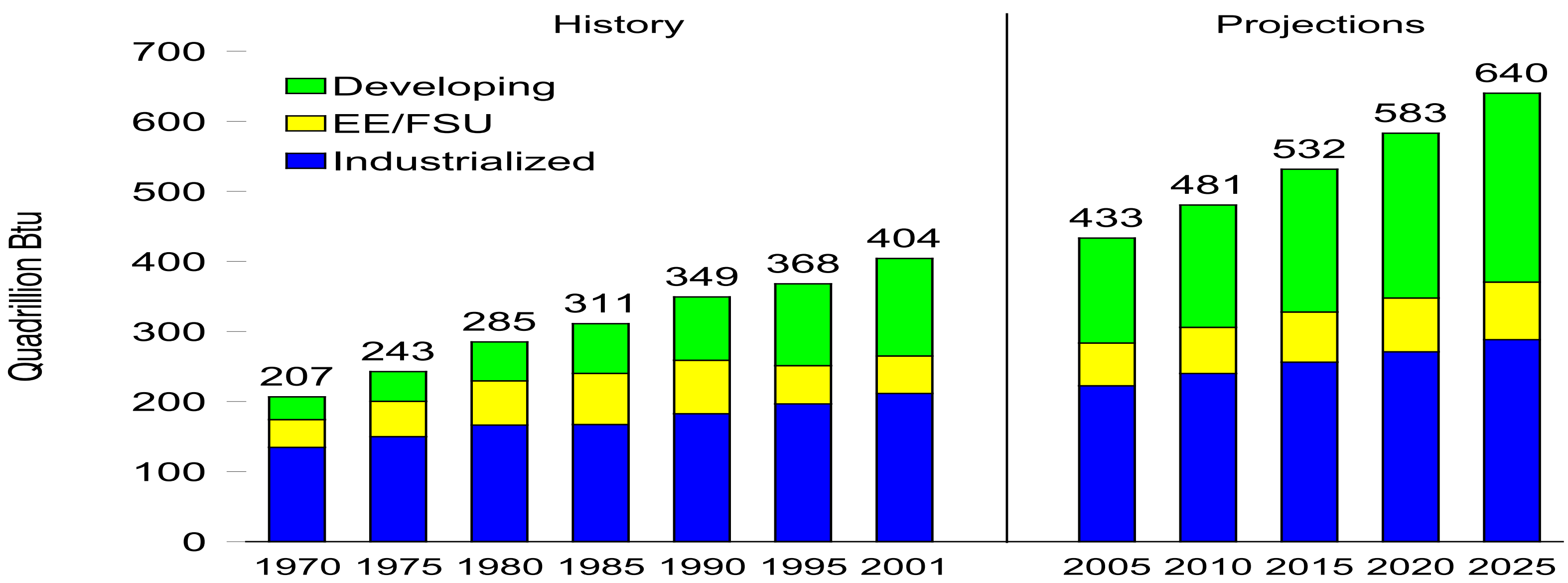


Source: NEI: Compiled from FERC data and EUCG industry reports

NEI

Energy demand growth is occurring globally and the greatest growth rates will be in the developing world

•



Internationally there are ongoing plans for nuclear energy expansion

- 33 countries with nuclear power plants
- Worldwide: 366 GWe installed, ~35 GWe currently under construction (~2%/year growth rate)
- Several countries pursuing advanced concepts, including fast reactors
- For example, China has a very aggressive nuclear energy plan
  - Present: 6.1 GWe
  - 2020: 32 GWe
  - 2030: 45-50 GWe
  - ~2050: 240 GWe

The management of nuclear materials and proliferation is a growing concern


Europe
Russia
North America
Asia
Africa
East Asia
West Asia
South America
International Nuclear Safety Center at ANL, Oct 2002

Tomorrow

So the debate about whether nuclear plants can compete with coal and gas-fueled plants is over. The answer is clearly yes.

But simply being competitive today will not meet our needs for tomorrow. To meet that demand, new plants must be built.

Will these be competitive?

The Near Term Challenges to Civliian Nuclear Power

Nuclear Power, circa 2004

The current performance of U.S. nuclear plants is excellent! Capacity factors are above 90%, safety has been superb, and nuclear generated electricity costs are now less than coal.

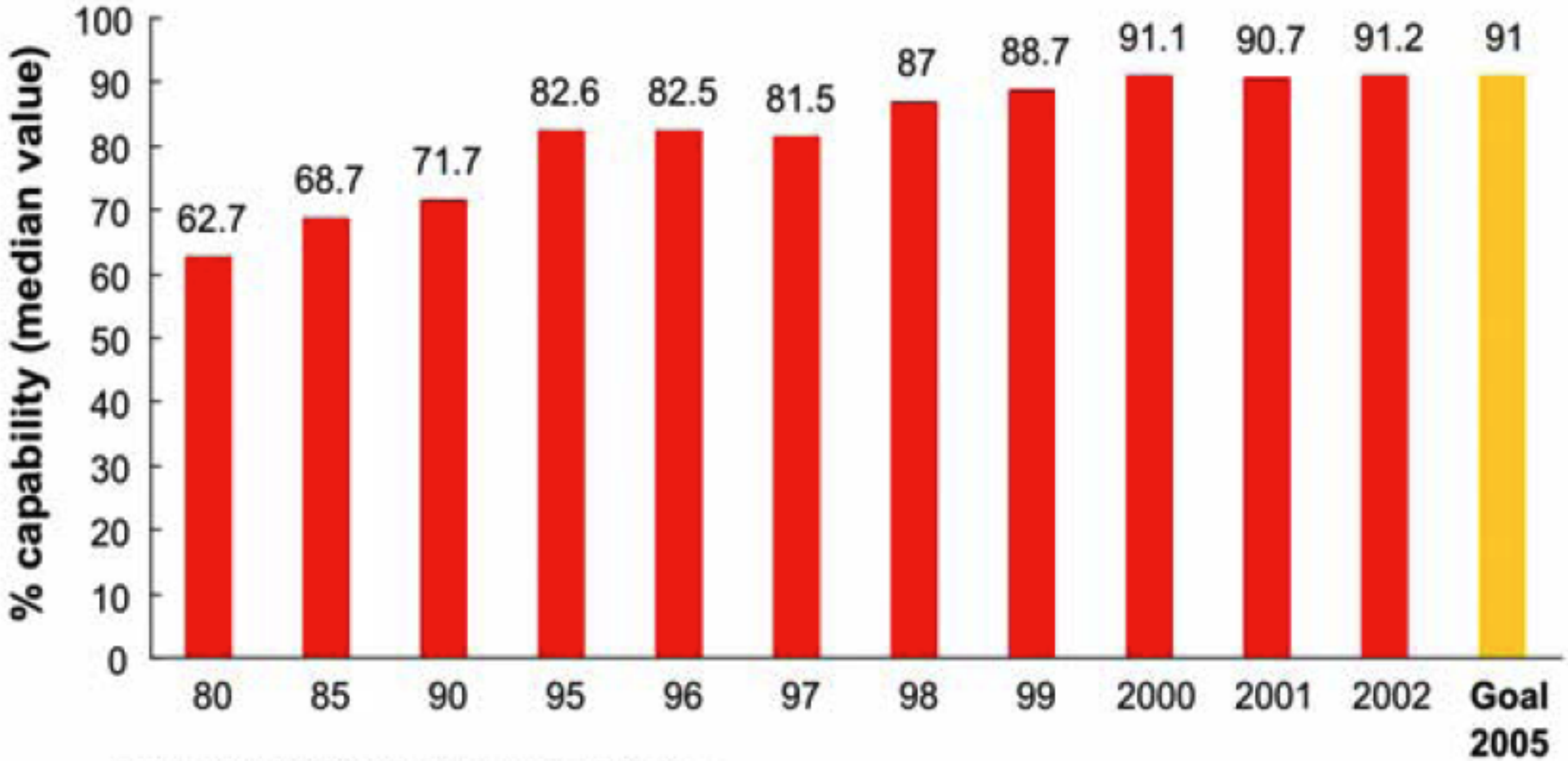
BUT, no nuclear plants have been ordered in the U.S. for 25 years, due to the capital intensive nature of plants, the long-term commitment required for construction, the financial risks, and most recently, the deregulation of the electricity marketplace.

Key Criteria for Success

- Nuclear plant "time to market" is a key factor affecting economic competitiveness in the deregulated marketplace. Long lead times prior to construction and long construction periods reduce economic competitiveness and increase project risks.
- Resolution of licensing issues before project commitment is essential to ensuring acceptably short lead-times.

The 2002 result is better than the 2005 goal and marks the third consecutive year that unit capability tops 90 percent.

This indicator measures a plant's ability to stay on line and produce electricity. Plants with a high unit capability are successful in reducing unplanned outages and improving planned outages.



Source: WANO 2002 Performance Indicators
Last Updated: 05/03

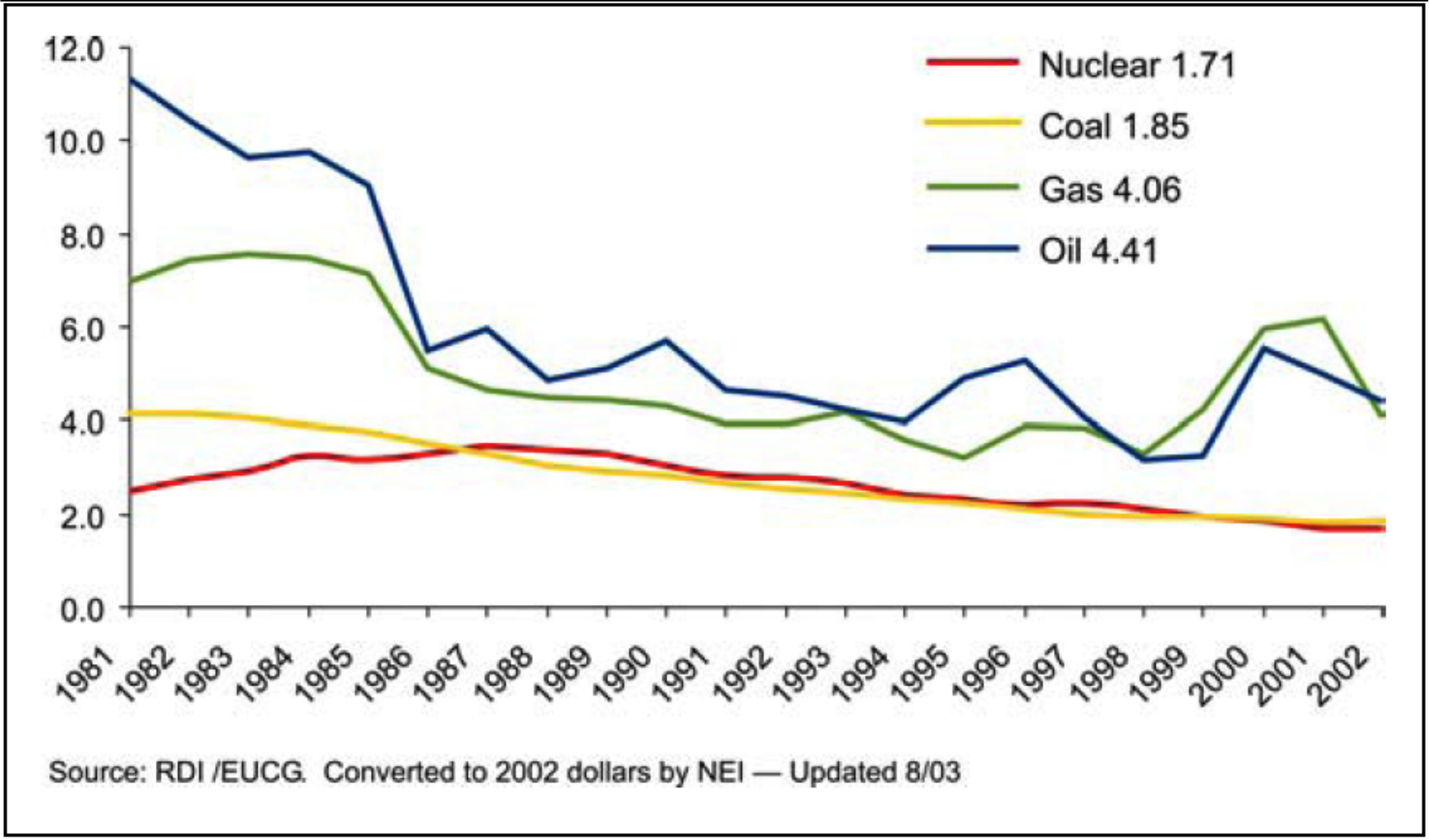


Figure 4: U.S. Electricity Production Costs (1981-2002) (in 2002 cents per kilowatt-hour)

University of Chicago Study

- Levelized cost of electricity (LCOE)
  - **Coal:** **3.3 to 4.1 cents/kWhr**
  - **Gas:** **3.5 to 4.5 cents/kWhr**
  - **FOAKE Nuclear:** **4.7 to 7.1 cents/kWhr**
  - **Later Nuclear:** **3.1 to 4.5 cents/kWhr**
- NOTE: These numbers are for new Gen III nuclear plants (e.g., ALWR)

Achieving a Long Term Sustainable Future for Nuclear Power

Several issues are driving concerns related to the global uses of nuclear technology

Controlling nuclear materials: non-proliferation

Disposition of nuclear waste

Ensuring safety of materials and facilities

Achieving economic competitiveness

Addressing these issues is essential to achieving a total system approach to the expanded use of nuclear energy

Longer Term Goals

- Sustainability
- Economics
- Safety and reliability
- Proliferation resistance
- Physical protection

Sustainable Nuclear Energy

- The ability to meet the needs of the present generation while enhancing the ability of future generations to meet society's needs indefinitely into the future.
- Having a positive impact on the environment through the displacement of polluting energy and transportation sources by nuclear electricity generation and nuclear produced hydrogen.

Sustainability (cont)

- Allow geologic waste repositories to accept the waste of many more plant-years of nuclear plant operation through substantial reduction in the amount of wastes and their decay heat.
- Greatly simply the scientific analysis and demonstration of safe repository performance for very long time periods (beyond 1,000 years), by a large reduction in the lifetime and toxicity of the residual radioactive wastes sent to repository.

Sustainability (cont)

- Extending the nuclear fuel supply into future centuries by recycling used fuel to recover its energy content, and by converting U-238 into new fuel.

Competitive Nuclear Energy

- Achieving economic life-cycle and energy production costs through a number of innovative advances in plant and fuel cycle efficiency, design simplifications, and plant sizes.
- Reducing economic risk to nuclear projects through innovative advances that may be possible with the development of plants using innovative fabrication construction techniques and modular plants.

Competitive (cont)

- Allowing the distributed production of hydrogen, fresh water, district heating, and other energy products to be produced where they are needed.

Safe and Reliable Systems

- Increasing the use of inherent safety features, robust designs, and transparent safety features that can be understood by nonexperts.
- Enhancing public confidence in the safety of nuclear energy.

Proliferation Resistance

- Providing continued effective proliferation resistance of nuclear energy systems through the increased use of intrinsic barriers and extrinsic safeguards.
- Increasing physical protection against terrorism by increasing the robustness of new facilities

Where Are We Today?

Some terminology

- Generation I: Early experiments (Shippingport, Big Rock Point, Fermi I, etc.)
- Generation II: 103 LWRs currently in operation
- Generation III: Next generation technologies that are essentially available now (ABWR, AP-1000, SWR-1000, Advanced CANDU)
- Generation IV: Technologies for 2030 and beyond

The Lab Directors' Nuclear Energy Action Plan: Goal #1 addresses environmental security

Goal #1: Reduce air pollution and global climate risk and improve energy security by meeting an increasing fraction of future US and world energy needs through safe and economic nuclear energy solutions

Provide incentives to encourage industry to order a new nuclear power plant by 2008

With advanced reactor technology, demonstrate hydrogen production by 2010-2012:
One pound of nuclear fuel = 250,000 gallons hydrogen equivalent

Goal #2 addresses spent fuel and radioactive waste

Goal #2: Achieve a 90% reduction of reactor waste requiring repository disposal by 2050 by significantly reducing the amount of uranium, plutonium, and minor actinides in disposed waste

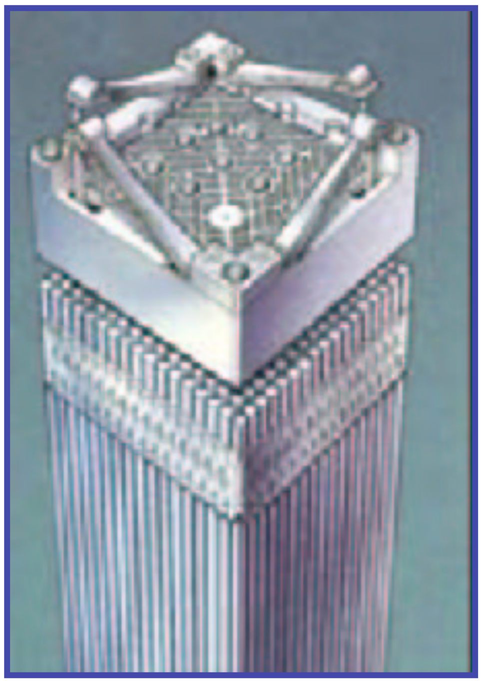
Construct pilot recycle and waste form facilities by 2010 to reduce waste

Construct a fast-spectrum reactor prototype by 2020 for electricity production and nuclear materials management

Goal #3 focuses on the reduction of proliferation risk

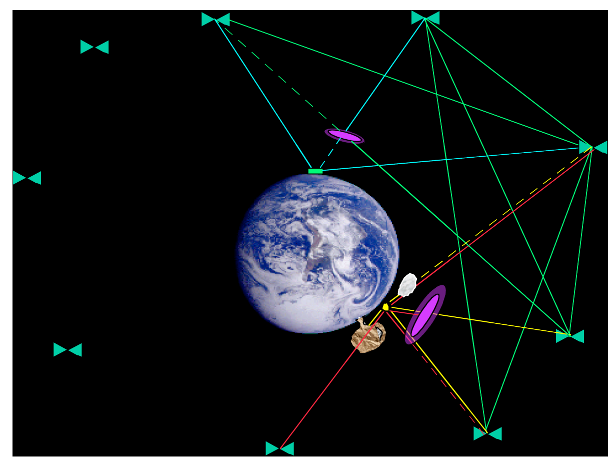
Goal #3: While expanding the use of nuclear technology worldwide, reduce the threat of nuclear weapons proliferation

Enable total system services through advanced materials management and very efficient exportable reactors



Demonstrate nuclear fuel recycle in an advanced reactor by 2020

Demonstrate a global nuclear materials management system by 2020



The Laboratory Directors recognized that non-proliferation requires a major emphasis

<u>**The DOE Laboratory Directors concluded that:**</u>

The time has come to develop a comprehensive and realistic plan to ensure the development and deployment of nuclear energy. It must preserve access to nuclear energy for all countries of the world, and in parallel, reduce the risks of nuclear arms proliferation, nuclear terrorism, and hazardous impacts on environment and population health.

New science and technology is necessary to implement non-proliferation policy

1. Enhanced safeguards for implementation of additional protocol
2. A new fuel-cycle paradigm is needed: supplier states & user states
3. Build on existing agreements from NPT and IAEA
4. Manage fresh fuel supplies and waste returns
5. Advanced nuclear systems are essential

   -- Reactors (long life cores, deep burn, etc.)

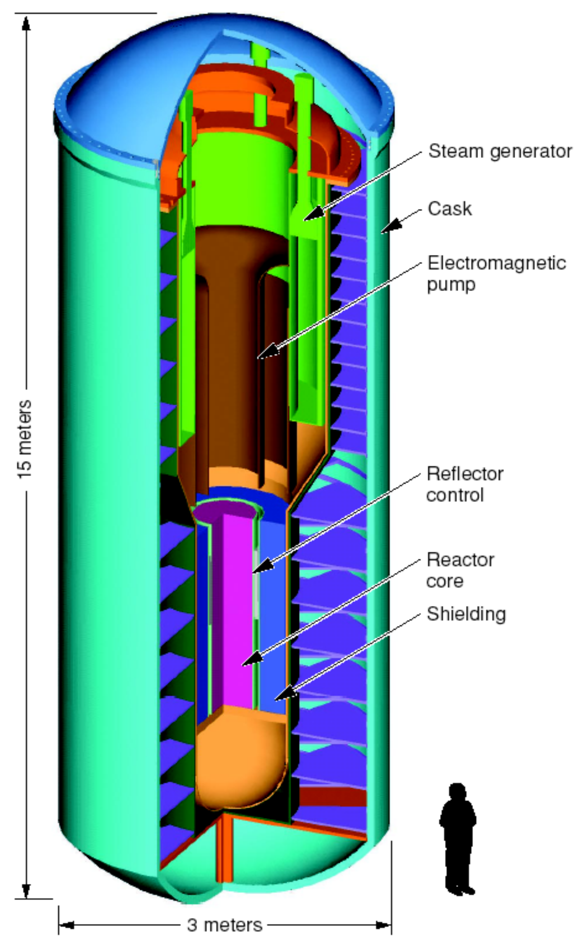
   -- Advanced fuels (unattractive for diversion)

   -- Fuel cycles (controls, actinide consumption)

   -- Integrated safeguards (sensors, information technologies)

   -- Waste management (cost effective, material efficient)

For example, the Small Secure Transportable Autonomous Reactor (SSTAR) offers novel approach



SSTAR is a concept being jointly developed by LLNL, ANL, and LANL

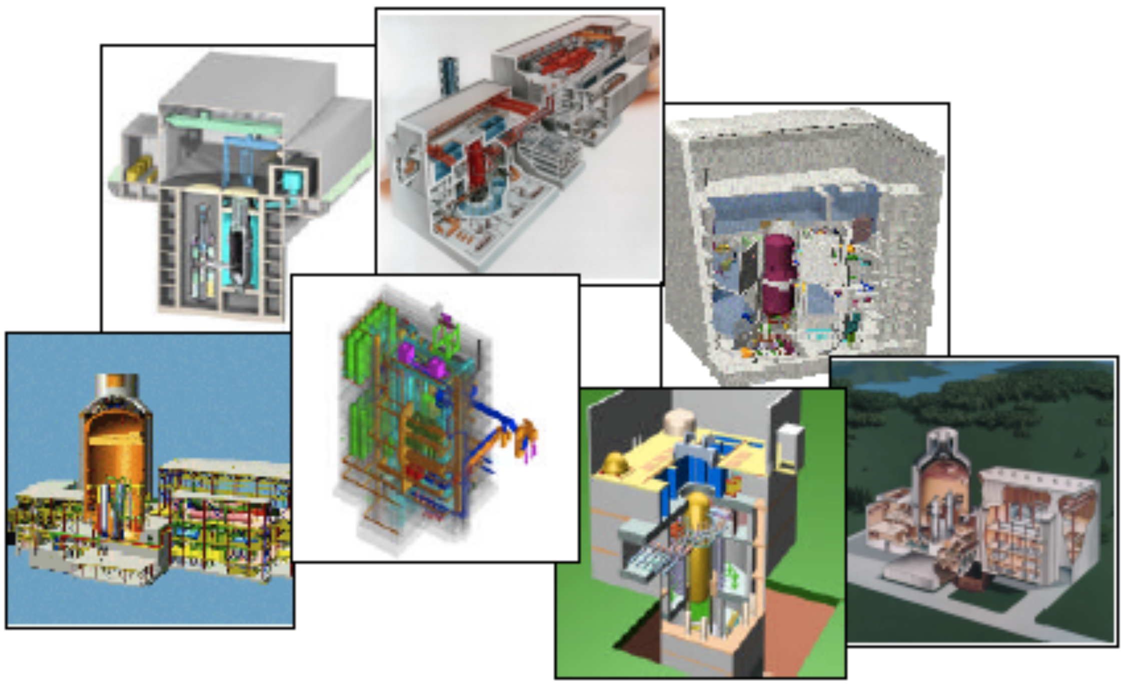
- **Sealed core: no on-site refueling**
- **Transportable: entire core and reactor vessel remain as a unit**
- **Long-life core: target is 30-year core life**
- **Simple integrated controls: minimum operator intervention or maintenance required**
- **Local and remote observability: rapid detection & response to perturbations**
- **Minimum industrial infrastructure required in host location**
- **Very small operational (and security) footprint**

Nuclear Power 2010

Nuclear Power 2010

is a new R&D initiative announced by Secretary Abraham on February 14, 2002. This initiative is designed to clear the way for the construction of new nuclear power plants by 2010.

Near Term Candidates



Can We Build New U.S. Reactors By 2010? *Yes!*

Can Be Deployed by 2010
- ABWR (General Electric)

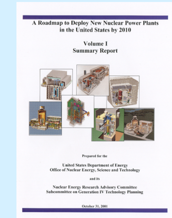
Probably Can Be Deployed by 2010
- AP600 (Westinghouse)
- AP1000 (Westinghouse)
- PBMR (Exelon)

Possibly Can Be Deployed by 2010
- SWR-1000 (Framatone)
- ESBWR (General Electric)
- GT-MHR (General Atomics)

Cannot Be Deployed by 2010
- IRIS (Westinghouse)

2010

Conclusions of the Expert Study: *A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010*



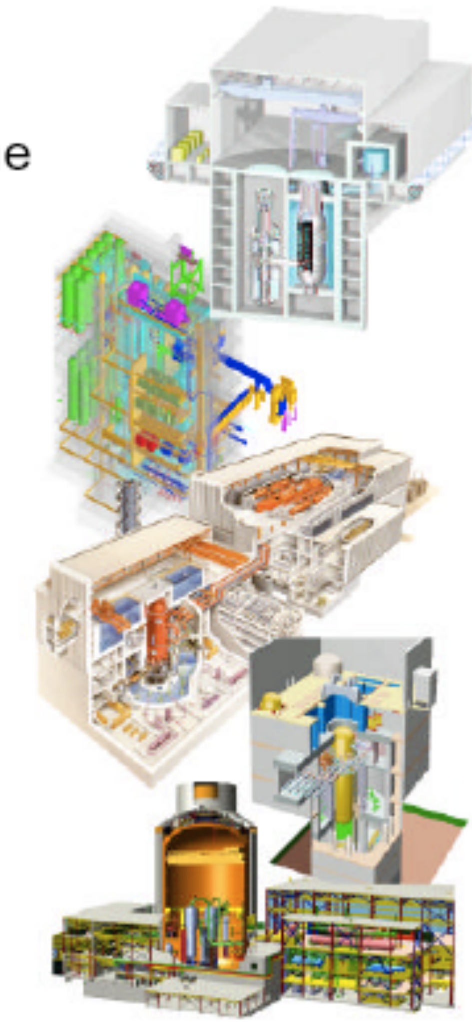
Nuclear Power 2010:
Overview

Goal

- Achieve industry decision by 2005 to deploy at least one new advanced nuclear power plant by 2010

Cooperative Activities

- **Regulatory Demonstration Projects**
  - Early Site Permit (ESP)
  - Combined Construction and Operating License (COL)
- **Reactor Technology Development Projects**
  - NRC Design Certification (DC)
  - First-of-a-kind engineering for a standardized plant
  - Material, component and system testing

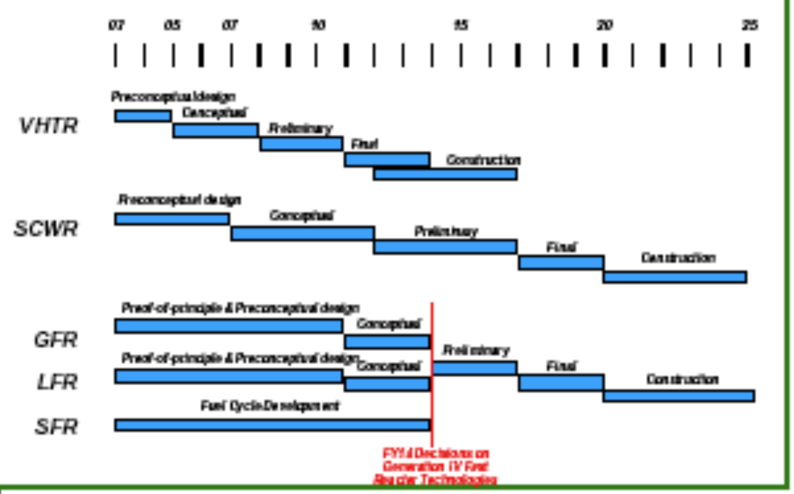


Nuclear Plant Licensing Demos

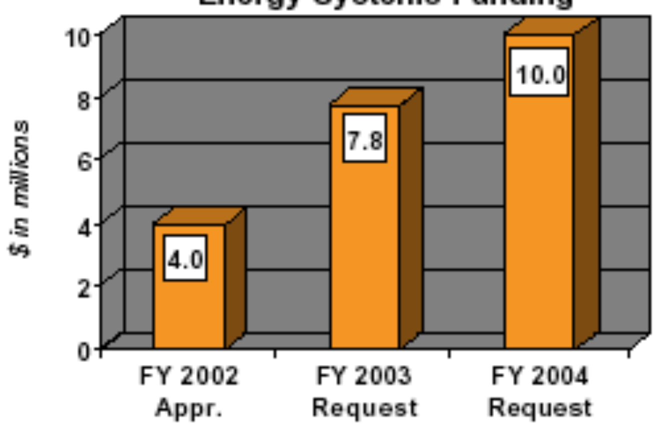
- Dominion Energy, AECL, Bechtel, Hitachi
  - **Two 700 MW Advanced CANDU reactors**
  - **North Anna**
- TVA, GE, GNF, Toshiba, Bechtel
  - **ABWR**
  - **Bellefonte**
- NuStart Energy (Excelon, Entergy, Duke, TVA, EDF, GE, Westinghouse
  - **AP-1000 and ESBWR**
  - **Site to be determined**

Generation IV Nuclear Energy Systems: *Nuclear Power for a New Century*

Potential Generation IV Timelines



Generation IV Nuclear Energy Systems Funding



- **Developing advanced nuclear energy systems for deployment after 2010 and before 2030**
- **In September 2002, the 10-Nation Generation IV International Forum agreed on 6 advanced technologies, including:**
  - Very High Temperature Reactor (VHTR)
  - Supercritical Water Cooled Reactor (SCWR)
  - Gas Cooled Fast Reactor (GFR)
  - Lead Cooled Fast Reactor (LFR)

Planned Accomplishments -- FY 2004

- **Conduct major VHTR trade studies**
- **Complete feasibility study on GFR fuels studies**
- **Initiate mechanical and irradiation tests on advanced materials**

Generation IV Technology Roadmap

NERAC Meeting: Washington, D.C.
September 30, 2002

Generation IV Technology Roadmap

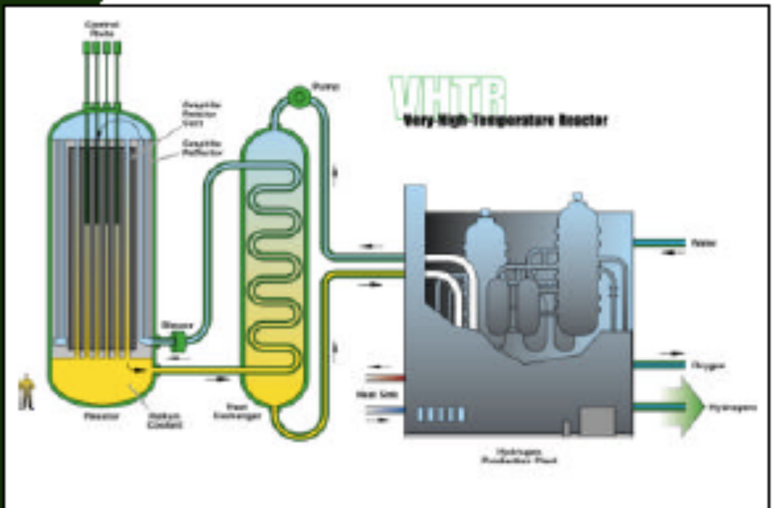
- Identifies systems deployable by 2030 or earlier
- Specifies six systems that offer significant advances towards:
  - Sustainability
  - Economics
  - Safety and reliability
  - Proliferation resistance and physical protection
- Summarizes R&D activities and priorities for the systems
- Lays the foundation for Generation IV R&D program plans

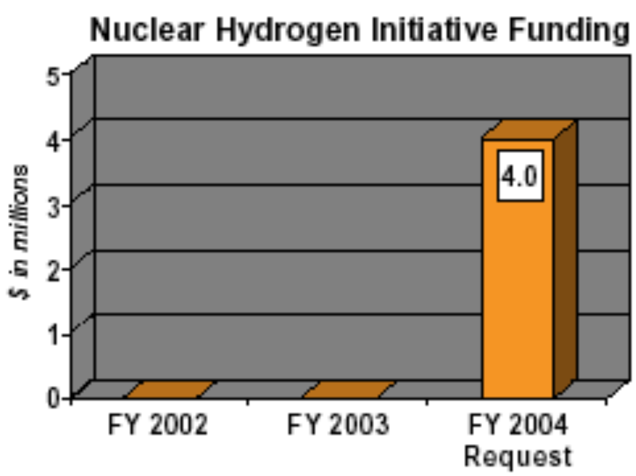
Generation IV Systems

Gas-Cooled Fast Reactor System	GFR
Lead-Cooled Fast Reactor System	LFR
Molten Salt Reactor System	MSR
Sodium-Cooled Fast Reactor System	SFR
Supercritical-Water-Cooled Reactor System	SCWR
Very-High-Temperature Reactor System	VHTR

- *Each system has R&D challenges ahead – none are certain of success*

Nuclear Hydrogen Initiative: *Developing Nuclear Energy Systems for Clean and Abundant Hydrogen Production*





? Nuclear energy systems offer opportunity for economical, clean, and abundant source of hydrogen

<u>Planned Accomplishments in FY 2004</u>

? Complete a Nuclear Hydrogen Technology Roadmap

- Built on National Hydrogen Energy Roadmap and inter-office cooperation
- Define R&D required to develop an integrated nuclear hydrogen production plant

? Develop concept for an integrated nuclear hydrogen production system

? Initiate R&D on high temperature and corrosion resistant materials for thermo-chemical process

Radioactive Waste

1000 Mwe-yr Power Plant Emissions

	COAL	GAS	NUCLEAR
Sulfur-oxide	~ 1000 mt		
Nitrous-oxide	~ 5000 mt	400 mt	
Particulates	~ 1400 mt		
Trace elements	~ 5-50 mt**	<1 mt	
Ash	~ 1million mt		
CO_2	> 7million mt	3.5mill. mt	

** TRACE: e.g., Chlorine, Lead, Cadmium, Arsenic, Mercury

	COAL	GAS	NUCLEAR
Spent Fuel			30-35 mt
Fission Products			1-1.5 mt

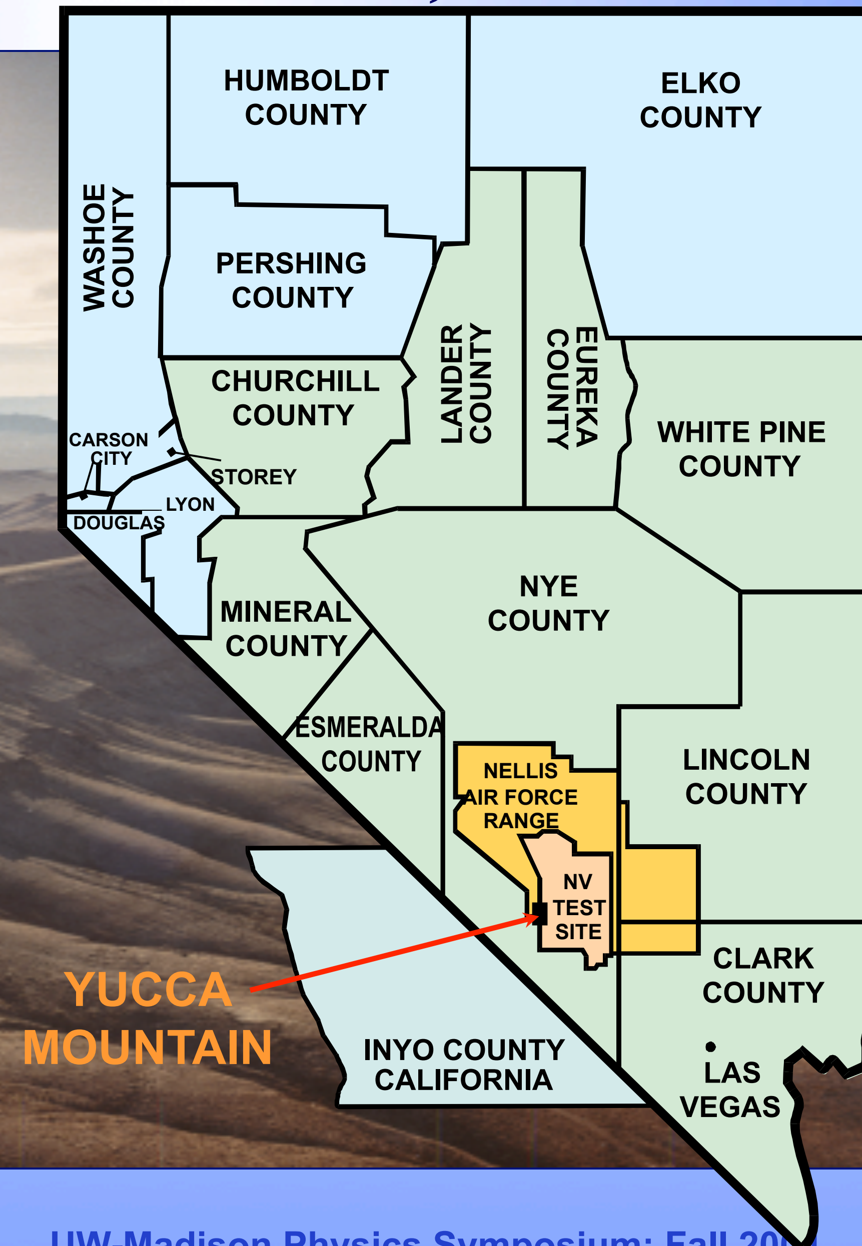
Nuclear Power High Level Waste (HLW)

- All nuclear fuel cycle waste (except HLW) has been disposed of through DoE and NRC regulations; milling, enrichment, fabrication as low-level waste
- Since 1982, US law ‘defines’ spent nuclear fuel as HLW, since reprocessing has not occurred since 1976 (Japan & Europe is where reprocessing does occur)
- Spent fuel is currently stored at ~105 nuclear power plant sites (~ 2000 mt/yr; total ~40,000 mt) and planned to be stored/buried at one site in the US
- All nuclear electricity is taxed at 1mill/kwhre for the HLW fund (~$1 billion/yr; totaling >$20 billion collected and over $8 billion expended)

Location of Yucca Mountain, Nevada

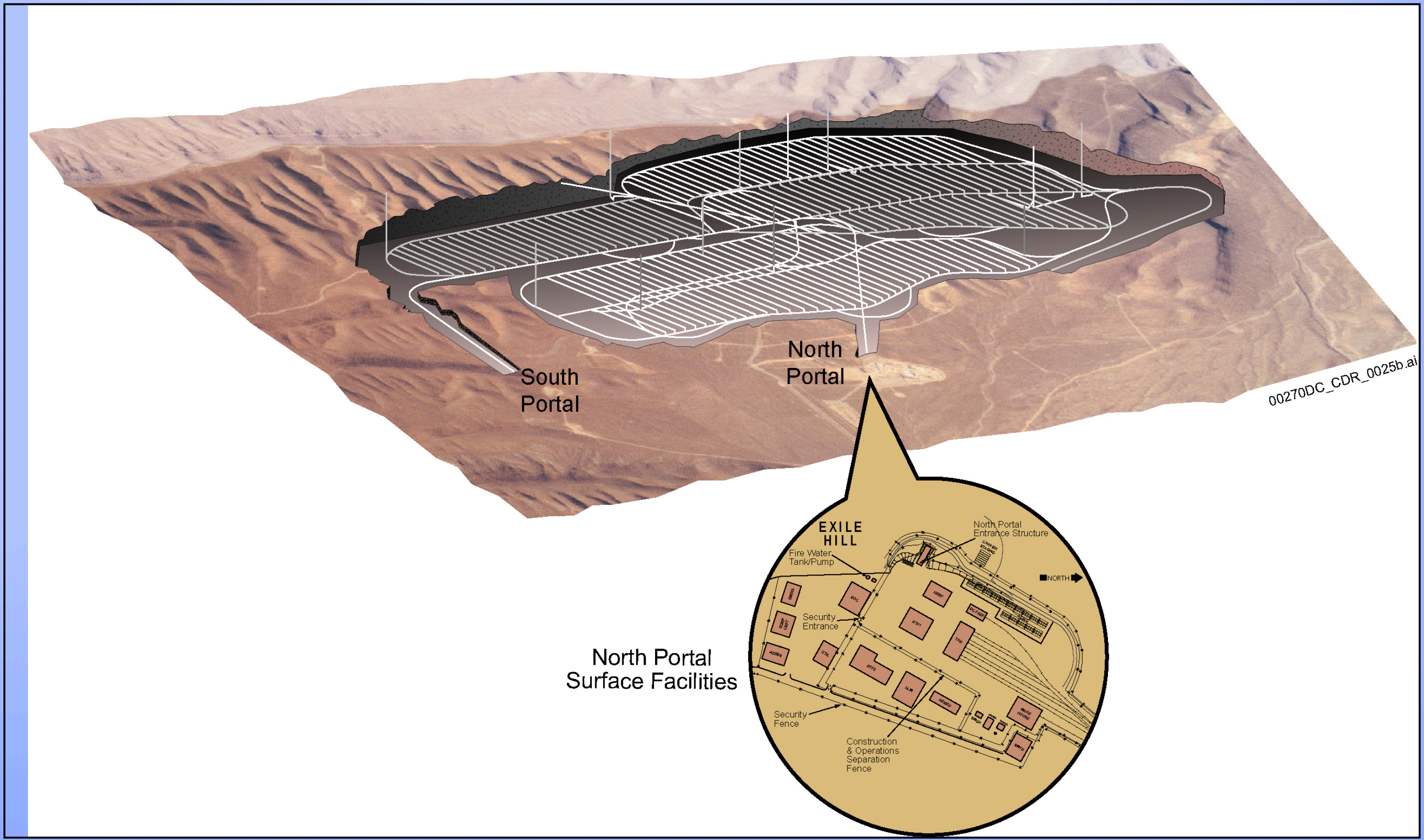
Counties designated as Affected Units of Local Government

- 100 miles northwest of Las Vegas in Nye County
- Located on western boundary of the Nevada Test Site, a DOE facility

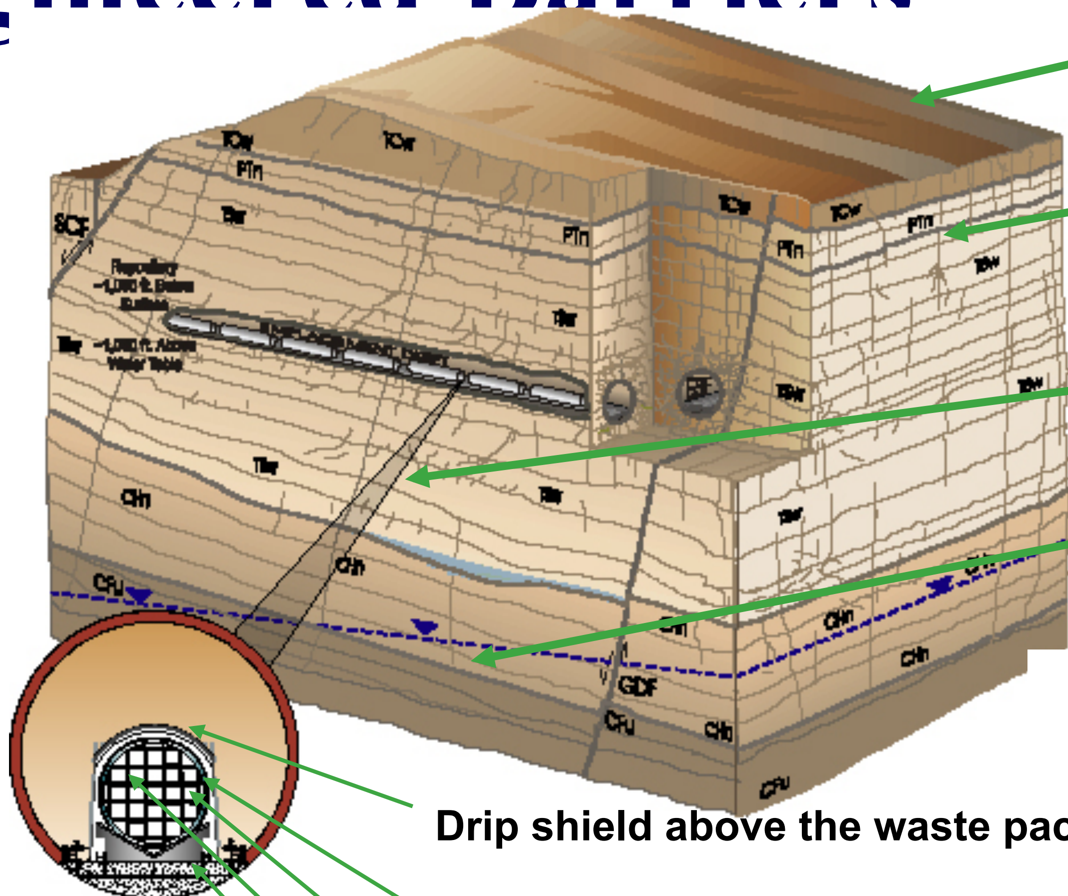


Repository Description

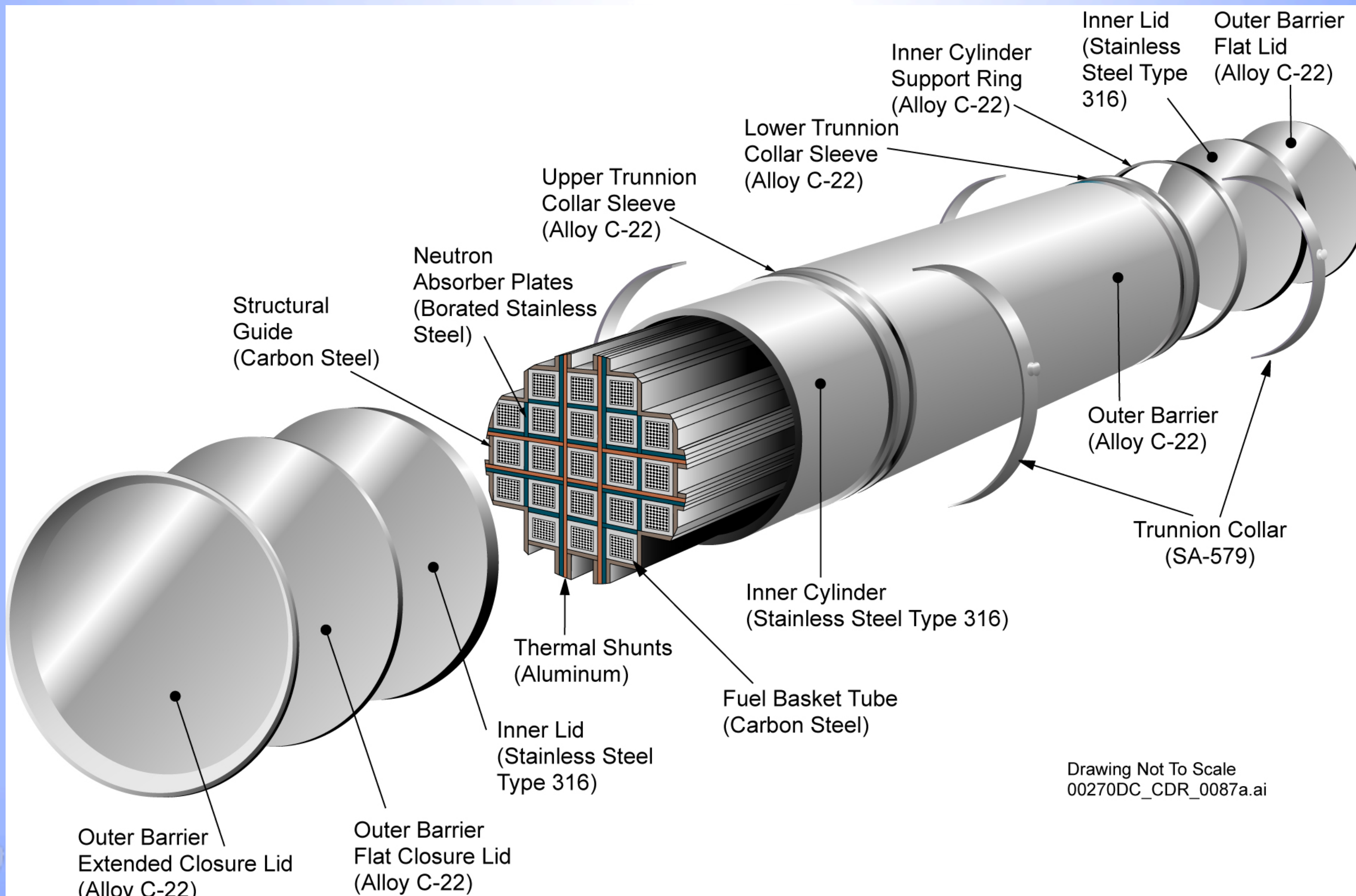
The Conceptual Design Report presents the facilities and structures that make up the repository and a description of repository operations. The figure below is a conceptual illustration of those facilities and structures that make up the repository upon completion.



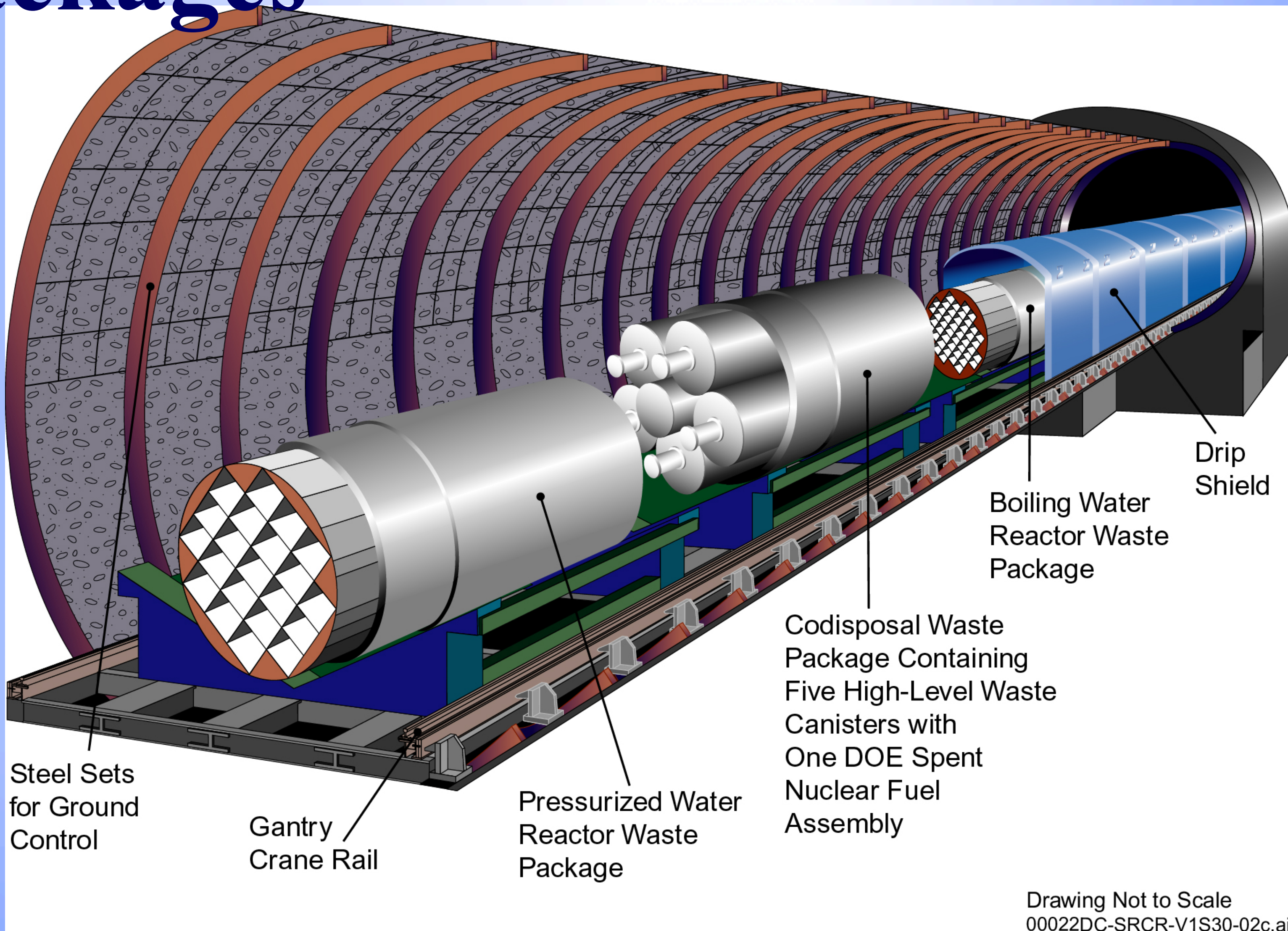
Repository Natural & Engineered Barriers



Waste Package



Cutaway of a Drift with Waste Packages



Current Issues

- Federal court is requiring EPA to develop compliance standard beyond 10,000 years
- Nevada congressional delegation has cut YMP budget in FY 2005
- Operational issues need to be addressed as part of engineering

Report to Congress

on

Advanced Fuel Cycle Initiative: The Future Path for Advanced Spent Fuel Treatment and Transmutation Research

DOE Advanced Fuel Cycle Initiative (AFCI)

While many countries are conducting advanced R&D on the management of spent fuel, the U.S. has done limited work since 1980. It is important for the U.S. to resume this research to ensure that advanced proliferation-resistant technologies become an integrated part of the management of spent fuel.

Advanced Fuel Cycle Initiative

- Reduce spent fuel volume by creating a final high level waste form that is lower in volume than original spent fuel.
- Separate long-lived, highly toxic elements (i.e., actinides such as Pu and Am) that present the most difficult disposition challenge.
- Reclaim spent fuel's valuable energy by providing a method to reclaim the energy value contained in the highly toxic spent fuel elements while providing for their destruction.

AFCI Series One

- Emphasizes advanced technologies applied to current reactor technology. Reduces the volume of material requiring geologic disposition by extracting the uranium (which represents 96% of spent fuel) and reducing the proliferation risk through the destruction of significant quantities of plutonium contained in spent nuclear fuel. These technologies could be deployed today.

AFCI Series Two

- Provides for complete resolution of radiotoxicity and heat load issues, by developing fuel cycle technologies for Gen IV systems aimed at enabling the commercial waste stored in a repository to be no more toxic than natural uranium ore after 1,000 years, while providing a very long-term sustainable fuel supply for expanded use of nuclear power (through very high conversion)

Some Final Concerns

Energy

The Current Situation

Importance of energy:

Energy costs typically absorb 7 to 10% of the cost of living (and are key factors in inflation and recession).

Energy is a major contributor to dangerous and complex environmental problems at every scale.

Energy issues can trigger issues in international security, from conflict over oil and gas reserves to nuclear weapons proliferation.

In 2000, more than 75% of world's energy was produced from fossil fuels.

Current Energy Supply System

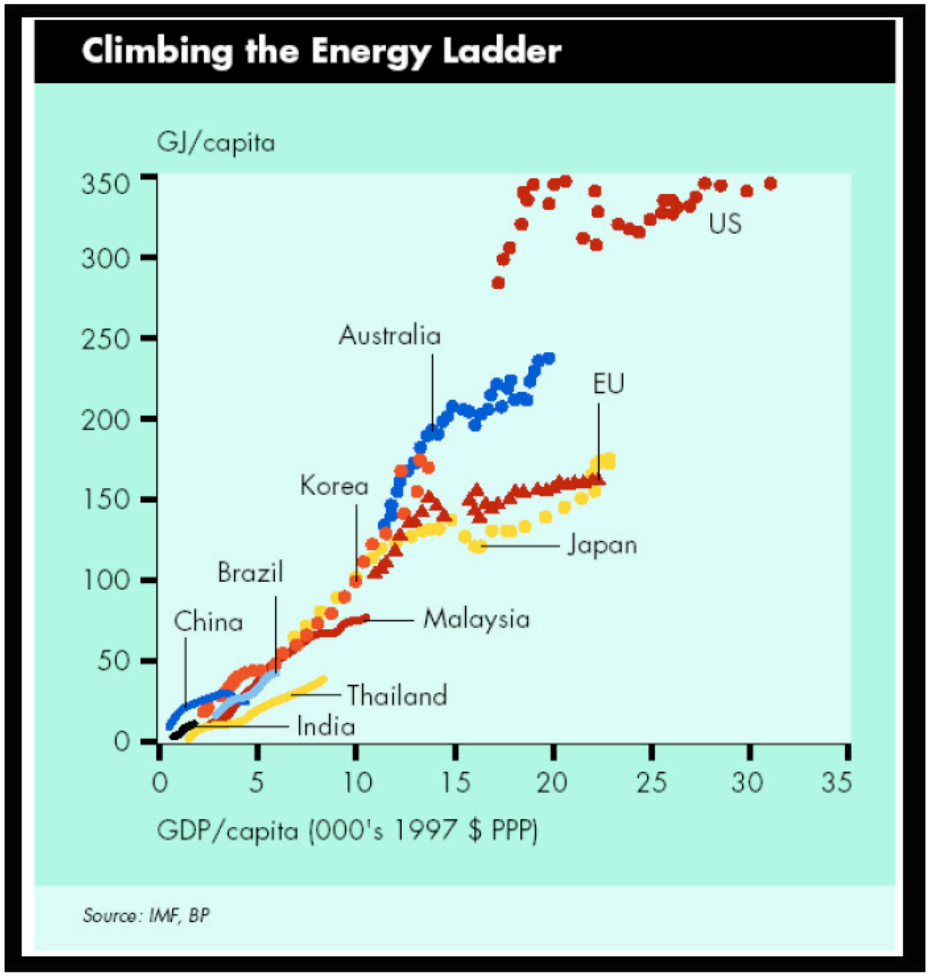
- In 2000, world's 6 billion people used about 450 exajoules (billion-billion or 10^18) (1 EJ ~ 1 quad = 10^15 BTU)
  - 35% from oil
  - 23% from coal
  - 20% from natural gas
  - 6% from nuclear power
  - 6% from hydropower
  - 13% from biomass fuels (e.g., wood)
- About 30% of primary energy was used to generate electricity. Fossil fuels provided 63%; nuclear provided 18%.
- The United States, with 4.5% of world's population, accounts for 23% of global energy use and 27% of electricity production.

Concerns

The reliability of energy supplies is decreasing because of political instability and increasing demand, at a time when many countries are becoming more dependent on those supplies. The United States is heavily dependent on foreign oil, and natural gas prices have doubled in recent months. Overall consumption of electrical power is increasing, and is likely to rise from 40% to 70% by 2050 (think computer!)

During the next decade, the role of renewables, particularly wind and biomass, will increase, but not nearly enough to fill present requirements. The U.S. and other developed countries will find it necessary to devote far more attention, including increased R&D, to multiple risk and energy trade-offs involving coal, nuclear power, petroleum, natural gas, and electric power.

Economic Prosperity Requires Reliable and Affordable Energy



Source: Royal Dutch Shell, "Exploring the Future – Energy Needs, Choices and Possibilities"

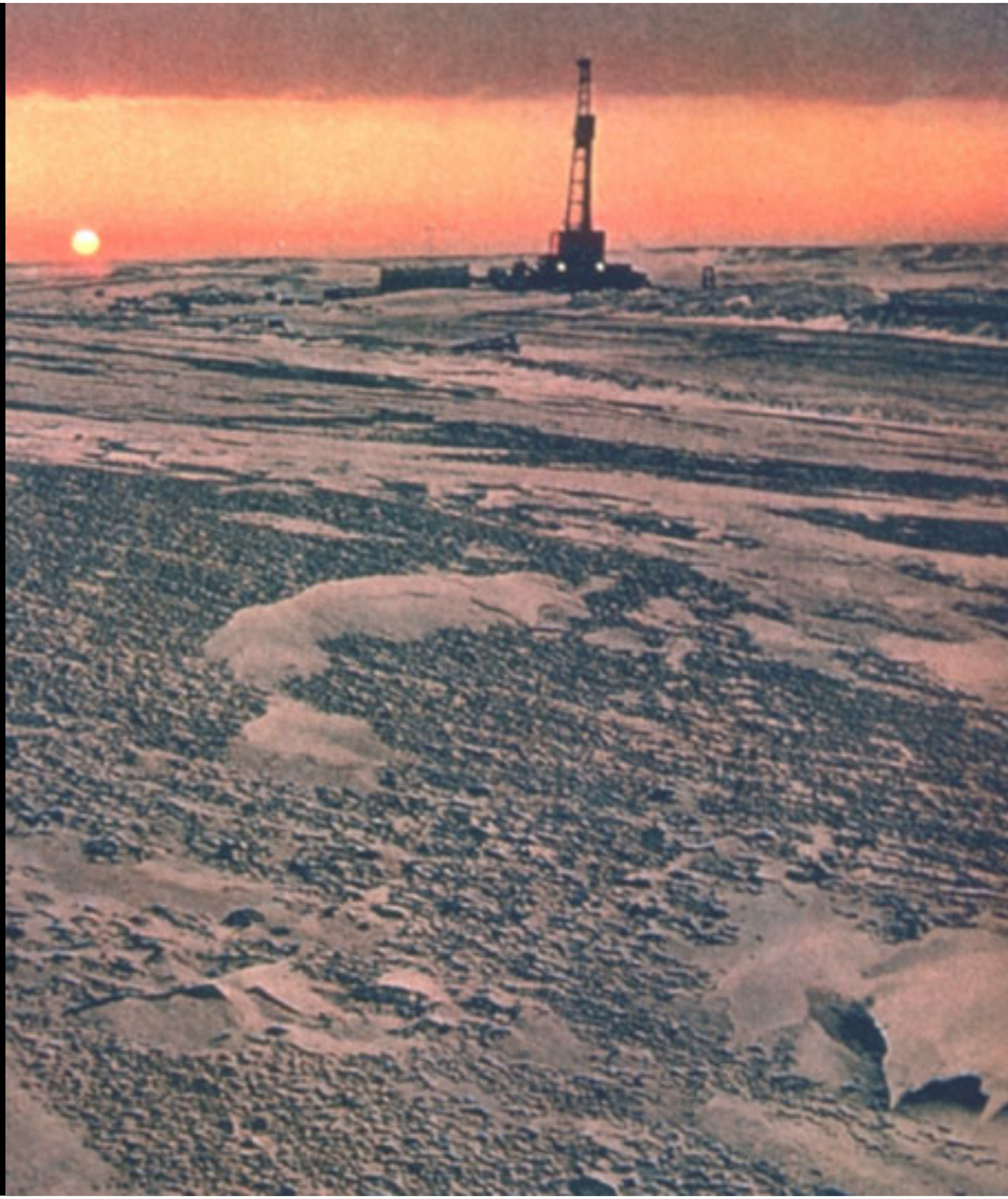
Sandia National Laboratories

Oil and gas

Exxon believes "that for the next 25 to 50 years, the oil available to the markets is for all intents and purposes infinite."

But scarcity is not the only reason why the world might move away from oil. The unnerving volatility of oil prices, together with growing concern about the environmental imapct of hydrocarbons, is already spurring the search for alternatives.

"The stone age did not end because the world ran out of stone, and the oil age will end long before the world runs out of oil!"



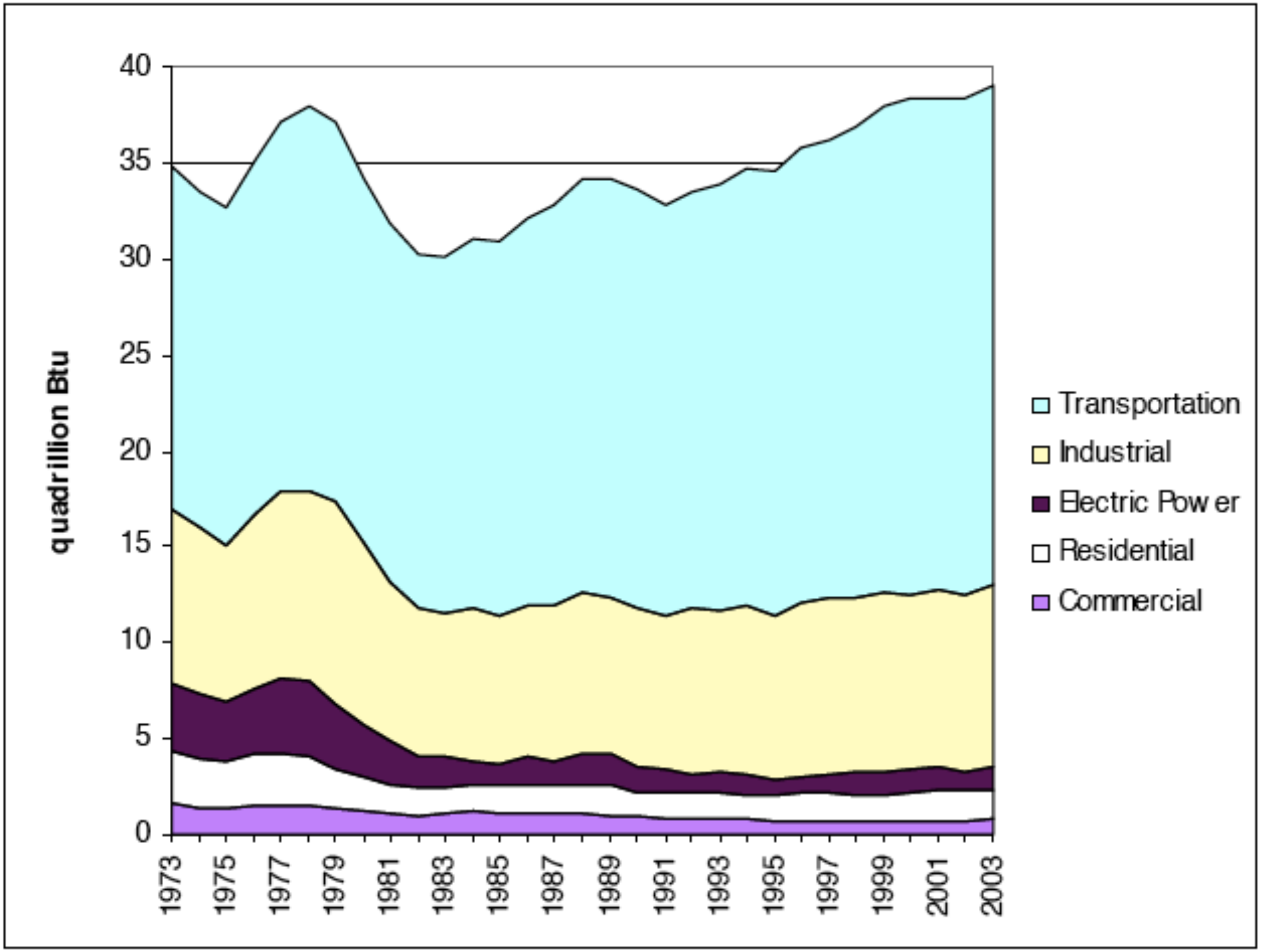


Figure III-1. U.S. Petroleum Consumption by Sector, 1973-2003[25]

M. King Hubbert's Peak

- U.S. oil production peaked in the 1970s
  - **The imbalance between domestic production and consumption has led to our extreme dependence on Middle East oil**
- When will global oil production peak?
  - **Certainly some time during this century.**
  - **Within next few decades?**
  - **Within next decade?**
- Note the disruption that will occur when global consumption exceeds production!

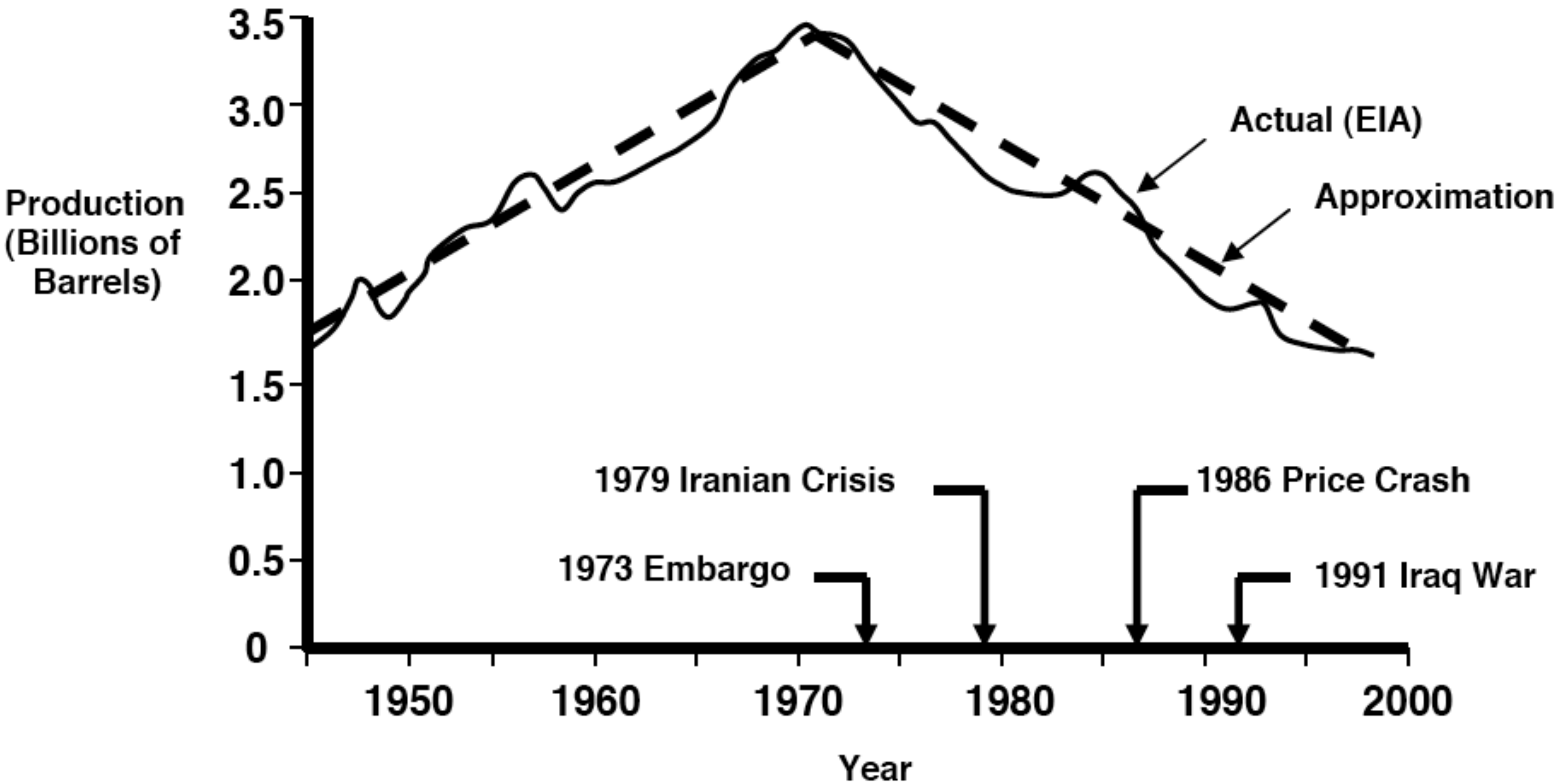


Figure II-2. U.S. Lower 48 Oil Production, 1945-2000


AFRAN ZODIAC

Table II-1. Projections of the Peaking of World Oil Production

Projected Date	Source of Projection	Background & Reference
2006-2007	Bakhitari, A.M.S.	Iranian Oil Executive[11]
2007-2009	Simmons, M.R.	Investment banker [12]
After 2007	Skrebowski, C.	Petroleum journal Editor [13]
Before 2009	Deffeyes, K.S.	Oil company geologist (ret.) [14]
Before 2010	Goodstein, D.	Vice Provost, Cal Tech [15]
Around 2010	Campbell, C.J.	Oil company geologist (ret.) [16]
After 2010	World Energy Council	World Non-Government Org.[17]
2010-2020	Laherrere, J.	Oil company geologist (ret.) [18]
2016	EIA nominal case	DOE analysis/ information[19]
After 2020	CERA	Energy consultants [20]
2025 or later	Shell	Major oil company [21]
No visible peak	Lynch, M.C.	Energy economist[22]

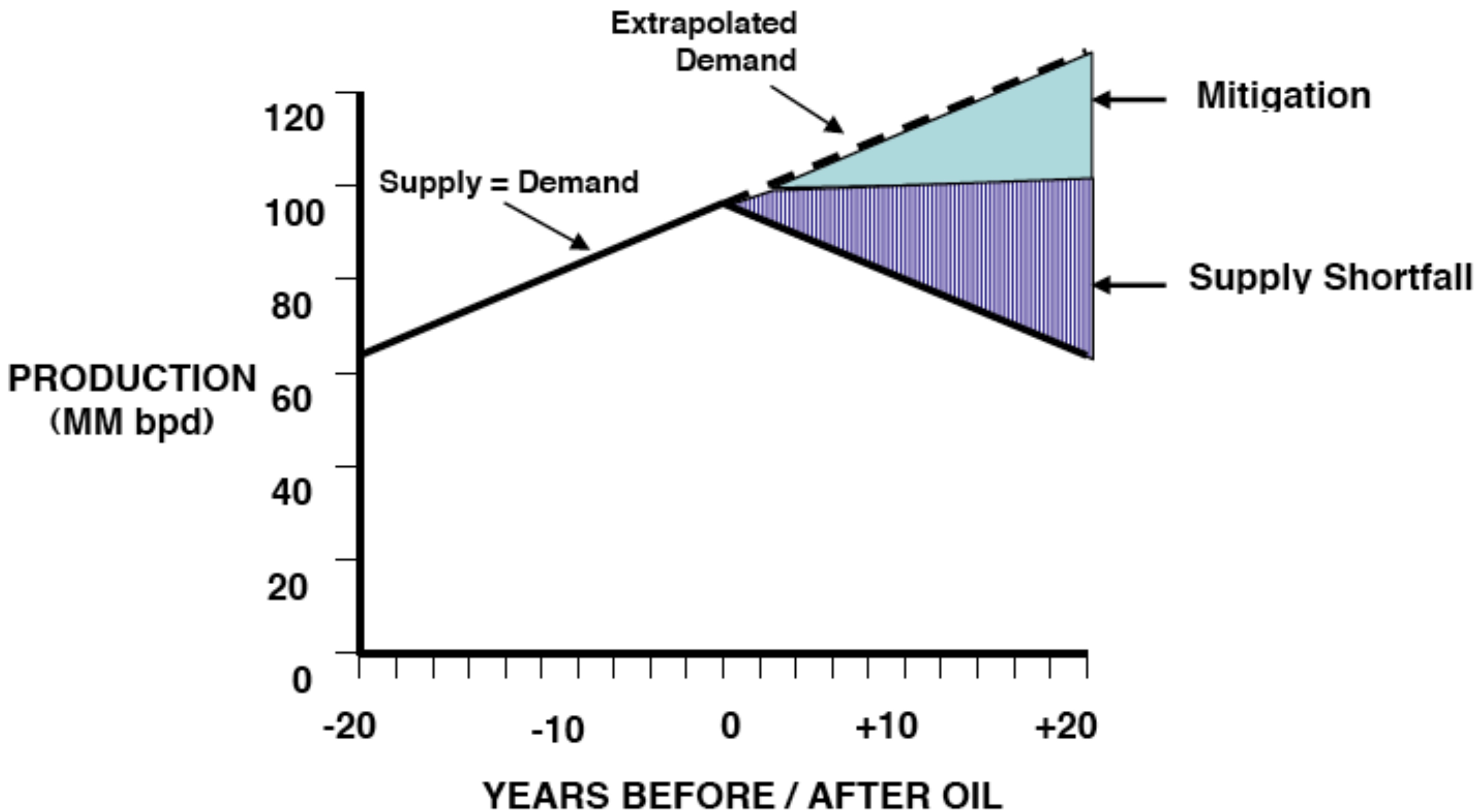


Figure VIII-4. Mitigation crash programs started at the time of world oil peaking: A significant supply shortfall occurs over the forecast period.

Global Sustainability

State of the Planet

“A dynamic interactive system of bio-geo-chemical cycles that are being significantly influenced by an emerging intelligent life-form.

This life-form has some serious limits in cognition and self-awareness as well as a number of other intellectual and physical constraints.”

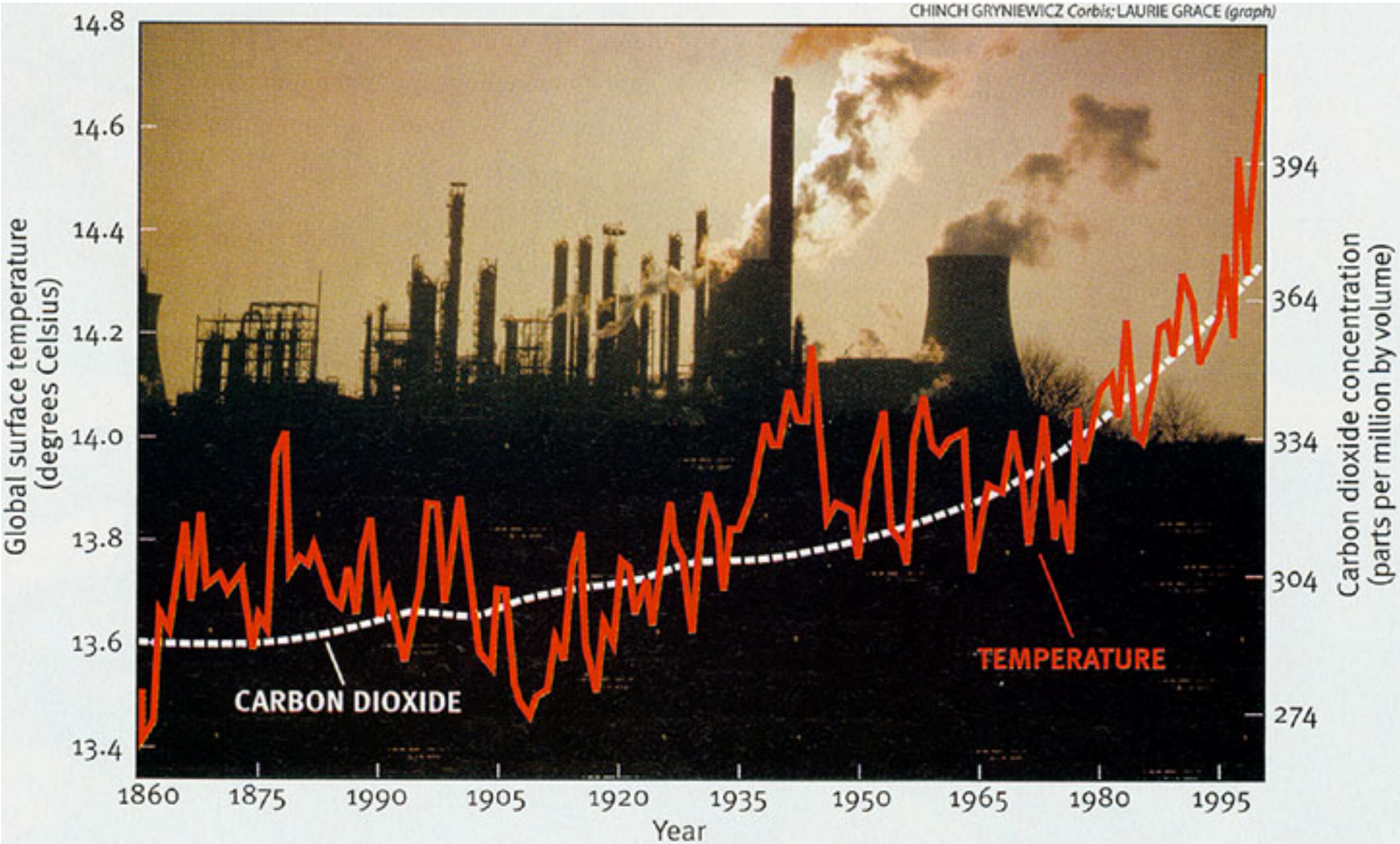
Michael Crow

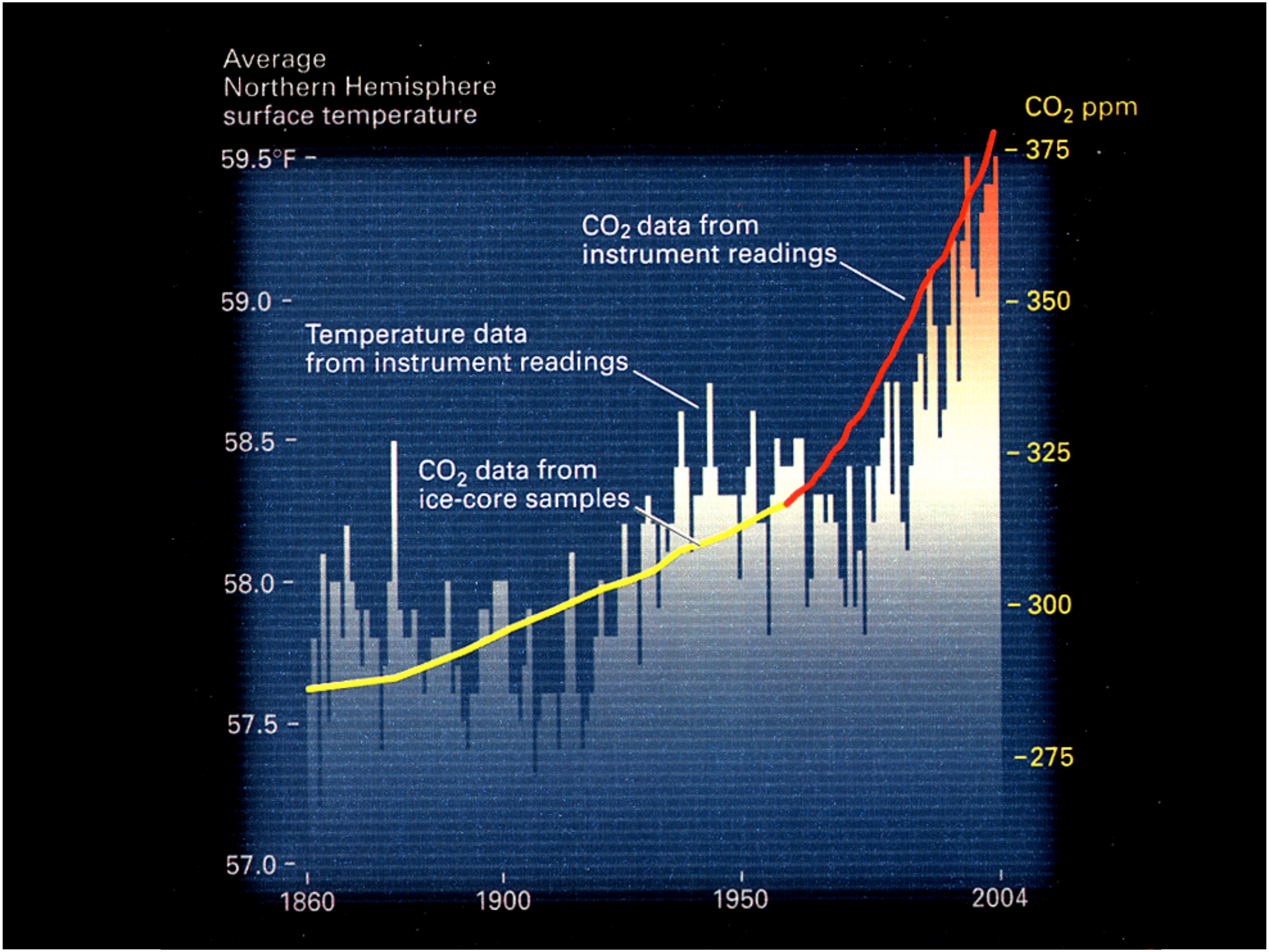
Global Climate Change

- There is compelling evidence that the growing population and invasive activities of humankind are now altering the fragile balance of our planet.
- The concerns are both multiplying in number and intensifying in severity: the destruction of forests, wetlands, and other natural habitats by human activities leading to the extinction of millions of biological species and the loss of biodiversity; the buildup of greenhouse gases such as carbon dioxide and their possible impact on global climates; the pollution of our air, water, and land.
- "Humanity's capacity to shape the planet has become more profound that our ability to recognize the consequences of our collective activity." Paul Ehrlich

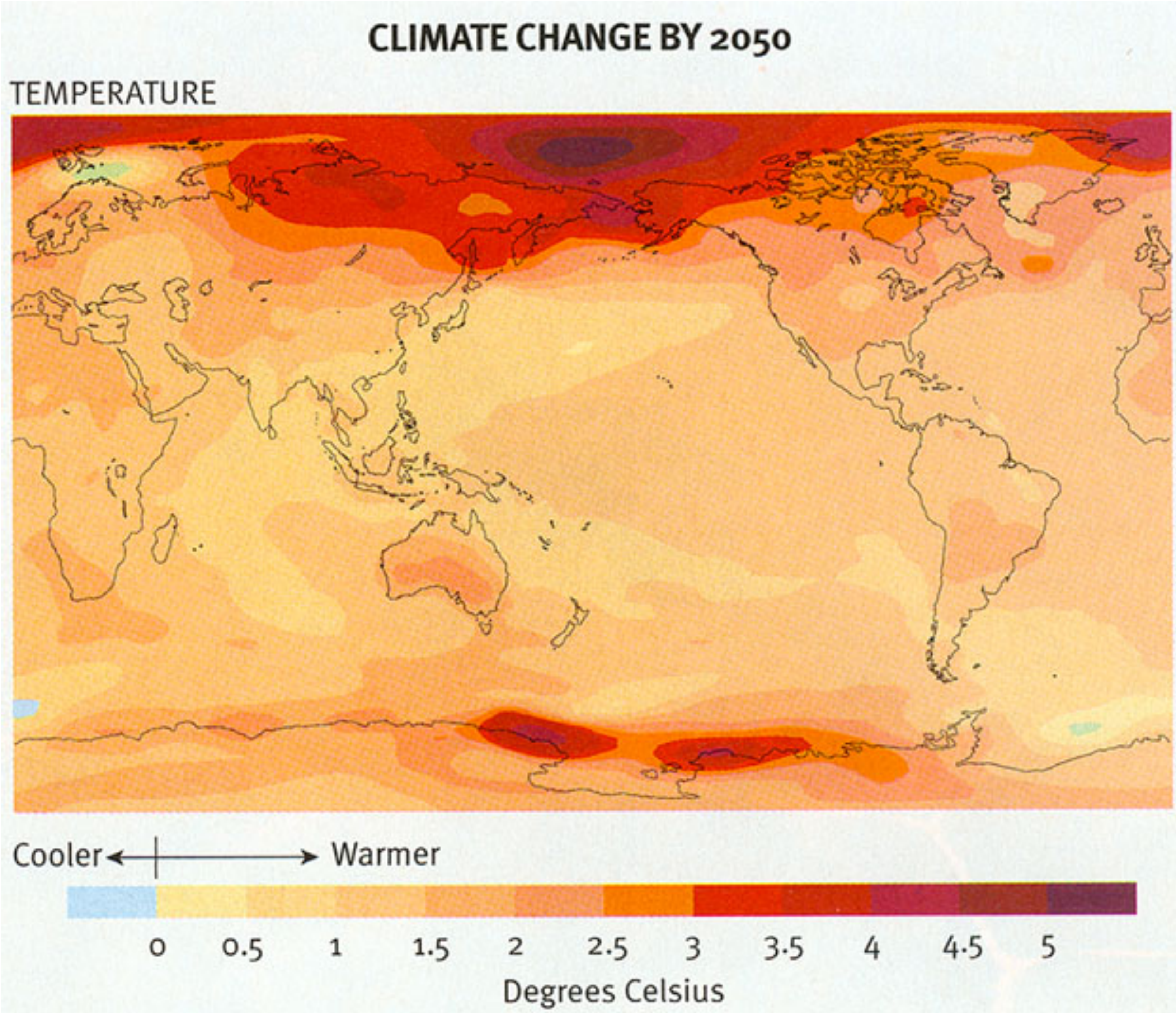
The Impact of Humankind

- For several decades, evidence has been mounting that human activity has caused a rapid increase in greenhouse gases (carbon dioxide, methane, nitrogen oxides), which in turn is causing the planet’s global temperature to rise.
- A 1.4 to 5.8 degrees C increase is predicted by the year 2100 -- a rapid and profound change. Even if the minimum predicted increase takes place, it will be larger than any century-long trend in the last 10,000 years.
- Rising global temperatures will cause major climate shifts and rising seas, among other environmental changes.


CHINCH GRYNIEWICZ Corbis; LAURIE GRACE (graph)
Global surface temperature (degrees Celsius)
14.8
14.6
14.4
14.2
14.0
13.8
13.6
13.4
Carbon dioxide concentration (parts per million by volume)
394
364
334
304
274
CARBON DIOXIDE
TEMPERATURE
1860
1875
1990
1905
1920
1935
1950
1965
1980
1995
Year



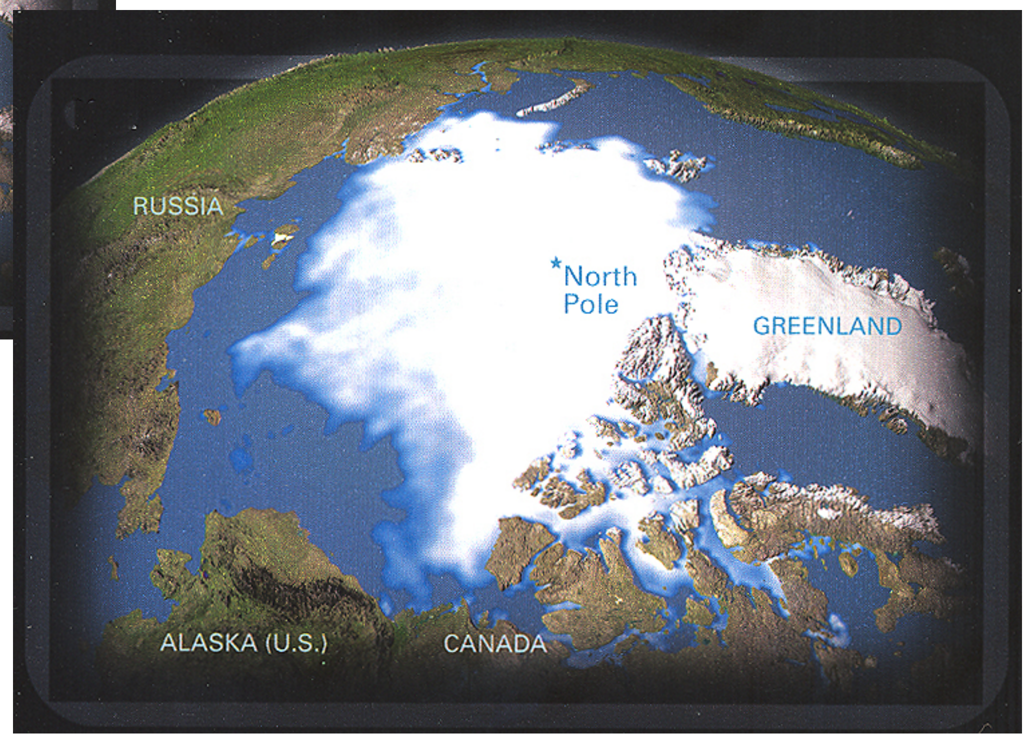
Average
Northern Hemisphere
surface temperature
CO_2 ppm
59.5°F
59.0
58.5
58.0
57.5
57.0
375
350
325
300
275
CO_2 data from
instrument readings
Temperature data
from instrument readings
CO_2 data from
ice-core samples
1860
1900
1950
2004


CLIMATE CHANGE BY 2050
TEMPERATURE
Cooler
Warmer
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Degrees Celsius

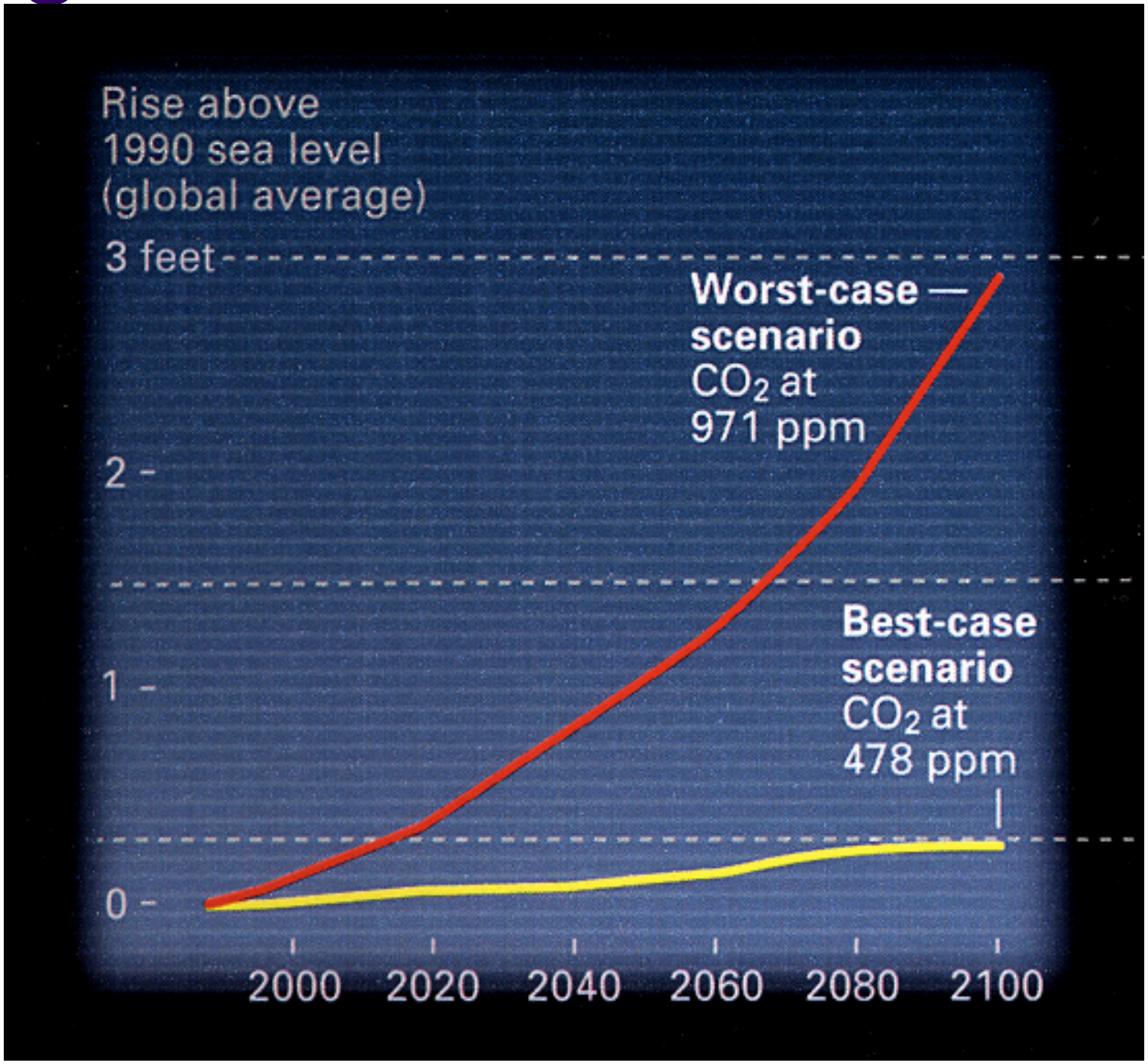
Arctic Ice Cap Change

1979

2003



Rising Sea Level



Impact of Humankind

"The balance of evidence suggests a discernible human influence on global climate."

Intergovernmental Panel on Climate Change,

United Nations

Most projections now suggest that the degree of change will become dramatic by the middle of the 21st century, exceeding anything seen in nature during the past 10,000 years.

How serious is this?

“The global climate change caused by human activity and above all by fossil fuel combustion is both the most dangerous and the most intractable environmental problem that civilization faces.

It is the most dangerous because climate creates the envelope of environmental conditions within which all other processes that operative in support of human well-being have to be able to function.

It is the most intractable of environmental problems because its fundamental changes are so deeply embedded in our way of life.”

John Holdren

What to do?

- It could well be that coming to grips with the impact of our species on our planet, learning to live in a sustainable fashion on Spaceship Earth, will become the greatest challenge of all to our generation. We must find new ways to provide for a human society that presently has outstripped the limits of global sustainability.
- This will be particularly difficult for the United States, a nation that has difficulty in looking more than a generation ahead, encumbered by a political process that generally functions on an election-by-election basis, as the current debate over global climate change makes all too apparent.

Climate Change and Kyoto Protocol

- The United Nations convened international meetings to discuss the challenges posed by global temperature and climate change.
- The Kyoto Protocol, a 1997 international agreement specifying action by nations to reduce greenhouse gas emissions, was developed at UN-sponsored meetings over many years.
- Many industrialized nations must reduce by 2012 greenhouse gas emissions 5%-8% below 1990 levels.

European Union	8% reduction (varies for each member country)
United States	7% reduction
Canada	6% reduction
Japan	6% reduction
Russia	No further growth in emissions
Norway	1% increase permitted

- Developing nations, including China and India, need not curb emissions during the 2008-2012 period.

U.S. Withdraws From Kyoto Protocol

- March 2001
  President Bush withdraws U.S. participation from Protocol, citing insufficient evidence for link between greenhouse gas (GHG) emissions and climate change, and the strain such limits would put on the U.S. economy.
- Feb. 16, 2005
  Protocol went into force following ratification by Russia, which brought the total number of signatories to the level required -- 55 nations (but which must also include nation's responsible for at least 55% of GHG emissions)
  Other nations that have ratified the Protocol include the European Union nations, Japan, China, India and Mexico.

What else can be done?

- Reduce the energy-intensive nature of our society (although this will be very difficult in view of the energy needs of developing nations).
- Reverse deforestation by planting trees and other CO-2 absorbing vegetation.
- Capture and store CO-2 (much as radioactive waste)
- Make a massive shift to non-carbon-emitting energy sources such as nuclear power, perhaps coupled with new technologies based on a hydrogen and a liquid fuel.

Decarbonized Fossil Fuels

- Recoverable, low-cost resources of conventional oil, gas, and coal are sufficient to meet world energy needs for at least another hundred years. Moreover, enormous quantities of unconventional fossil fuels--methane hydrates, oil shales, tar sands--could be extracted at somewhat higher prices or with improved technology.
- If the carbon contained in fossil fuels could be safely and inexpensively "decarbonized" or captured and sequestered, those fuels could continue to serve as a basis for world energy supply even while greenhouse gas concentrations are stabilized.

Approaches

- Capture: One might capture the CO_2 from large, centralized power sources such as coal-fired power plants. The technology using chemical solvents is mature but expensive, and likely to increase power costs by 100% or more.
- Conversion: To chemically convert fossil fuels into hydrogen and carbon dioxide. Again cost is an issue, currently about 70% greater than natural gas.
- Disposal: Over the next century this would create several hundred billion tons of CO_2 that would have to be sequestered from the atmosphere for at least several hundred years!

Summary

- Hydrogen and electricity are the only two non-carbon energy sources.
- Both need significant energy sources to produce them, and today, nuclear power is the only non-carbon emitting technology capable of massive expansion.
- In fact, since the energy payback on a nuclear plant is 4 years, it is increasingly clear that nuclear fission power presents one of the only realistic paths to a "hydrogen economy".

Conclusions

- Nuclear fission, which is the only technology widely deployed on a large scale today, still faces many challenges (waste displosal, proliferation, cost, public acceptance).
- Biomass is limited and would compete with food production and the preservation of natural ecosystems.
- Solar is benign but currently very expensive, and it would require massive energy storage and transmission facilities.
- Wind is competitive only in a few regions, and also would require storage and transmission.
- Fossil fuels are cheap and abundant, but the cost of capturing, transporting, and disposing of the carbon dioxide contained within them could be high with significant environmental impact.

The Role for Nuclear Power

- Although nuclear power produces one-sixth of the world's electricity, this is only 6% of total energy production.
- For nuclear power to have a major impact on global climate change, it would have to increase to 30% of world electric generation corresponding to 3,000 reactors of 1 GWe class.
- However, if nations could agree on a economic approach such as the use of carbon taxes such that the price of fossil fuels reflects the costs they impose on the environment and human health, the incentive for major expansion of nuclear power becomes enormous.

University of Chicago Study

- Levelized cost of electricity (LCOE)
  - **Coal:** **3.3 to 4.1 cents/kWhr**
  - **Gas:** **3.5 to 4.5 cents/kWhr**
  - **FOAKE Nuclear:** **4.7 to 7.1 cents/kWhr**
  - **Later Nuclear:** **3.1 to 4.5 cents/kWhr**
- For new Gen III nuclear plants (e.g., ALWR)
- If carbon tax is implemented:
  - **Coal:** **9.1 cents/kWhr**
  - **Gas:** **6.8 cents/kWhr**

The World

IAEA Conference: March, 2005

- Consensus: "Only by building more nuclear power stations can the world meet its soaring energy needs while averting environmental disaster."
- The Kyoto accord will force plant operators to pay for their pollution, making nuclear power facilities more competitive.

Europe

- One-third of Europe's electricity is nuclear, "saving greenhouse emissions equivalent to those of all of Europe's cars".
- Nuclear produces 78% of France's electricity.
- Finland has launched construction of a new nuclear plant.
- Italy has reversed its earlier decision to abandon nuclear power and is now considering building new nuclear plants (strongly supported by younger generation).

World

- Currently 440 commercial nuclear plants in more than 31 countries supplying 16% of world's electricity.
- IAEA predicts a 60% increase in demand for energy over next 25 years.
- (Note: At the moment, some 1.5 billion people do not have access to electricity. Without the nuclear option, this figure is unlikely to change over the next 25 years.)

Asia

- China: Will add 30 new nuclear plants by 2020 to 36 GW.
- India: Will increase nuclear power tenfold.
- Russia: Will double nuclear capacity to 45 GW.