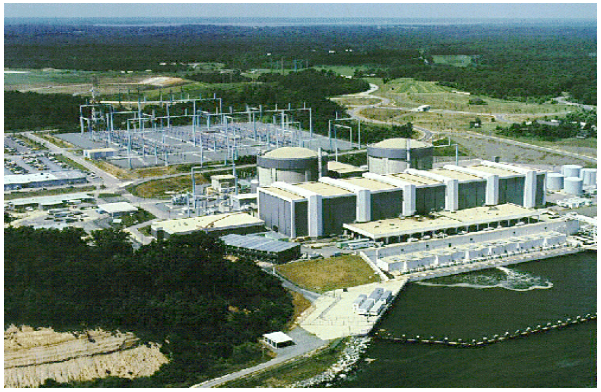
Nuclear Energy's Renaissance

Andrew C. Kadak
Professor of the Practice
Nuclear Science & Engineering Department
Massachusetts Institute of Technology

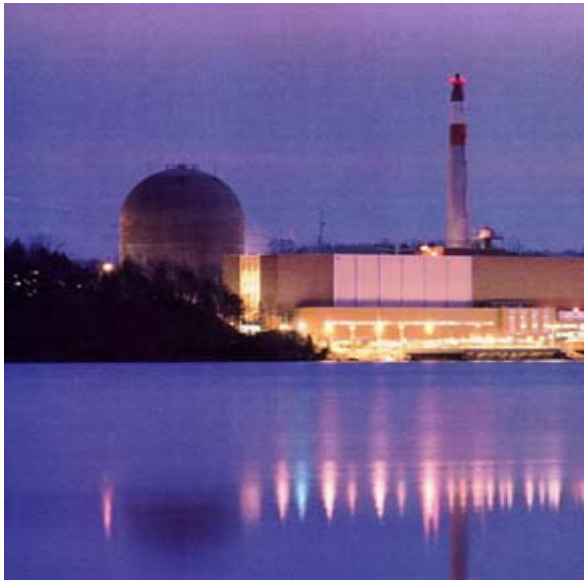
American Physical Society
October 2006

Background

- Nuclear energy supplies 20 % of US electricity demand –
- 104 Operating Nuclear Plants – performance at 90% capacity
- No new order since 1975
- 4 US vendors consolidated into three companies – Westinghouse, General Electric, AREVA
  - only 1 US owned.
- Public Support for nuclear at all time high
- Nuclear Plants making money for utilities

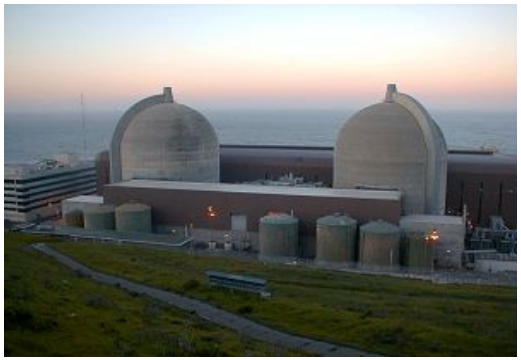


Calvert Cliffs - MD



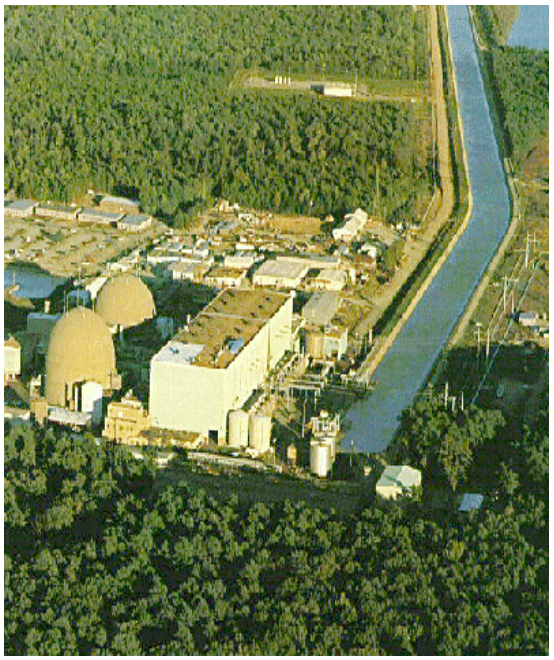
Indian Point - NY

Robinson - SC



Diablo Canyon

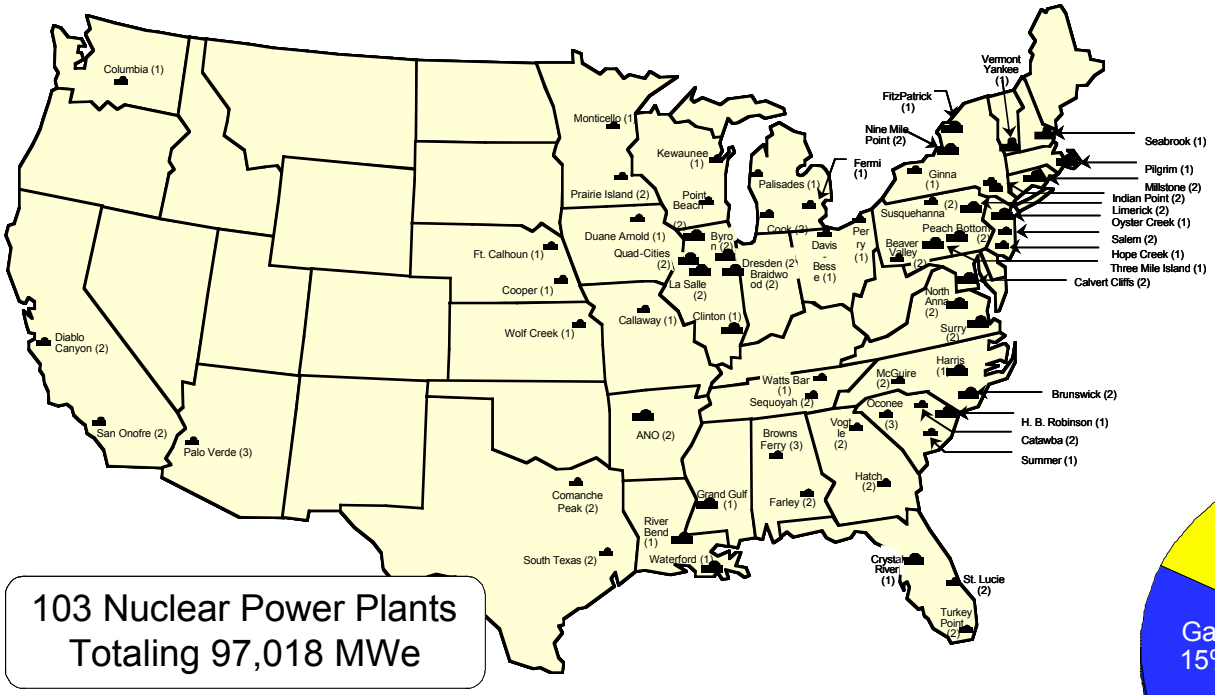
Prairie Island site - MN



Surry - VA

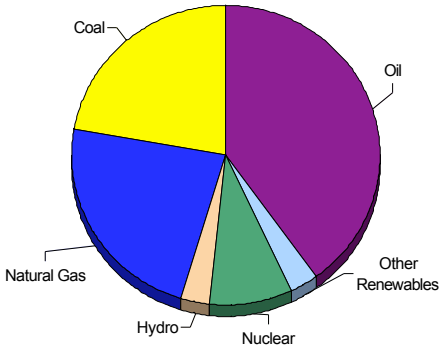
Prairie Island - MN

Today's nuclear needs

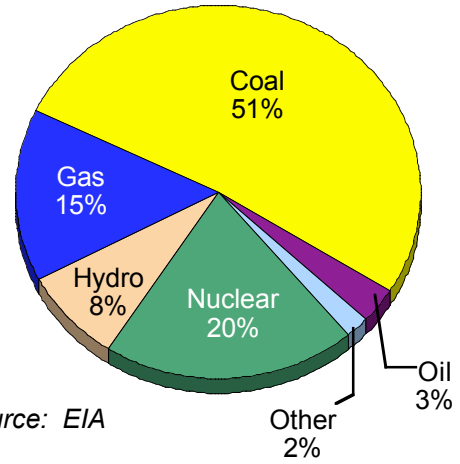


103 Nuclear Power Plants
Totaling 97,018 MWe

National Energy Policy calls for expansion of Nuclear Energy



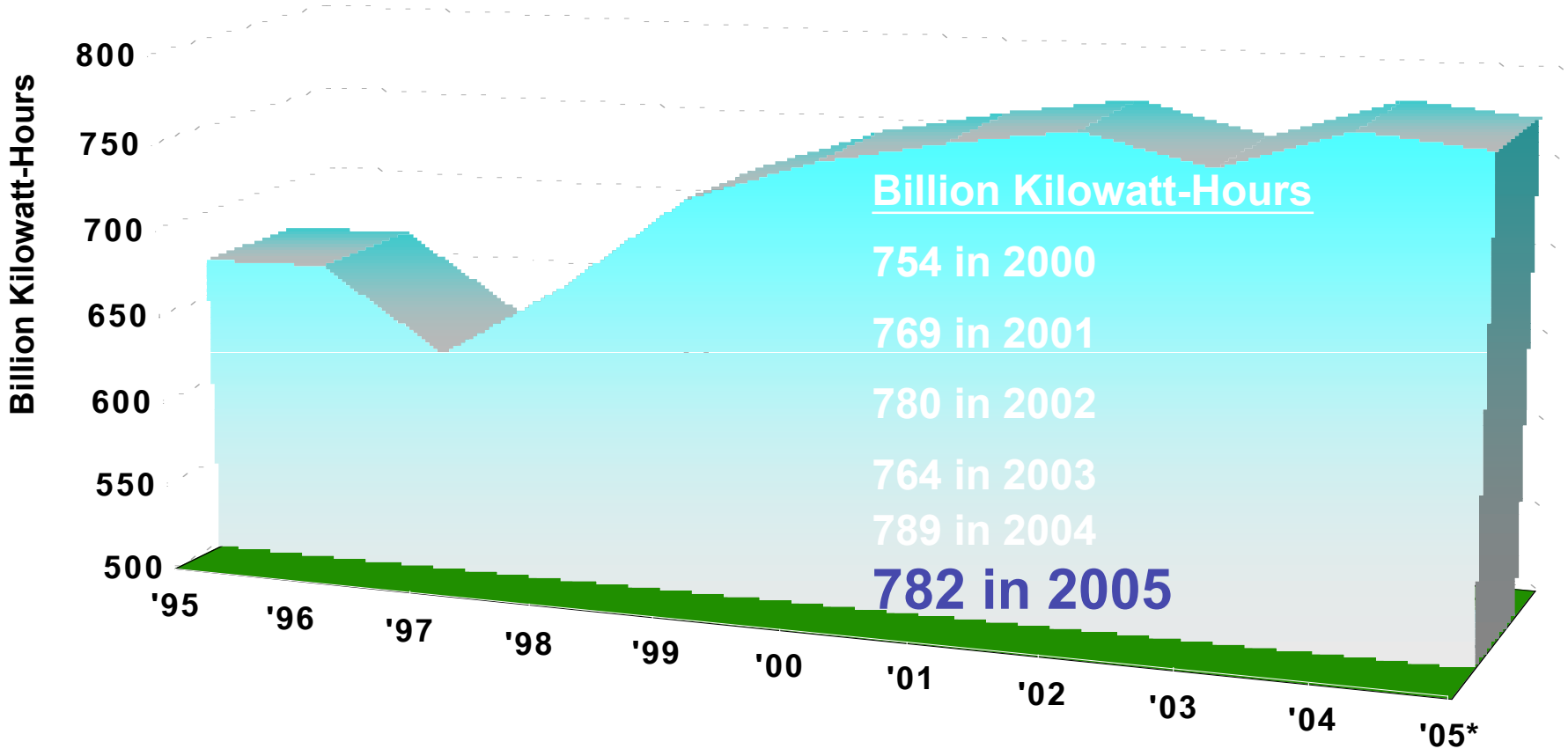
Energy Production



Source: EIA

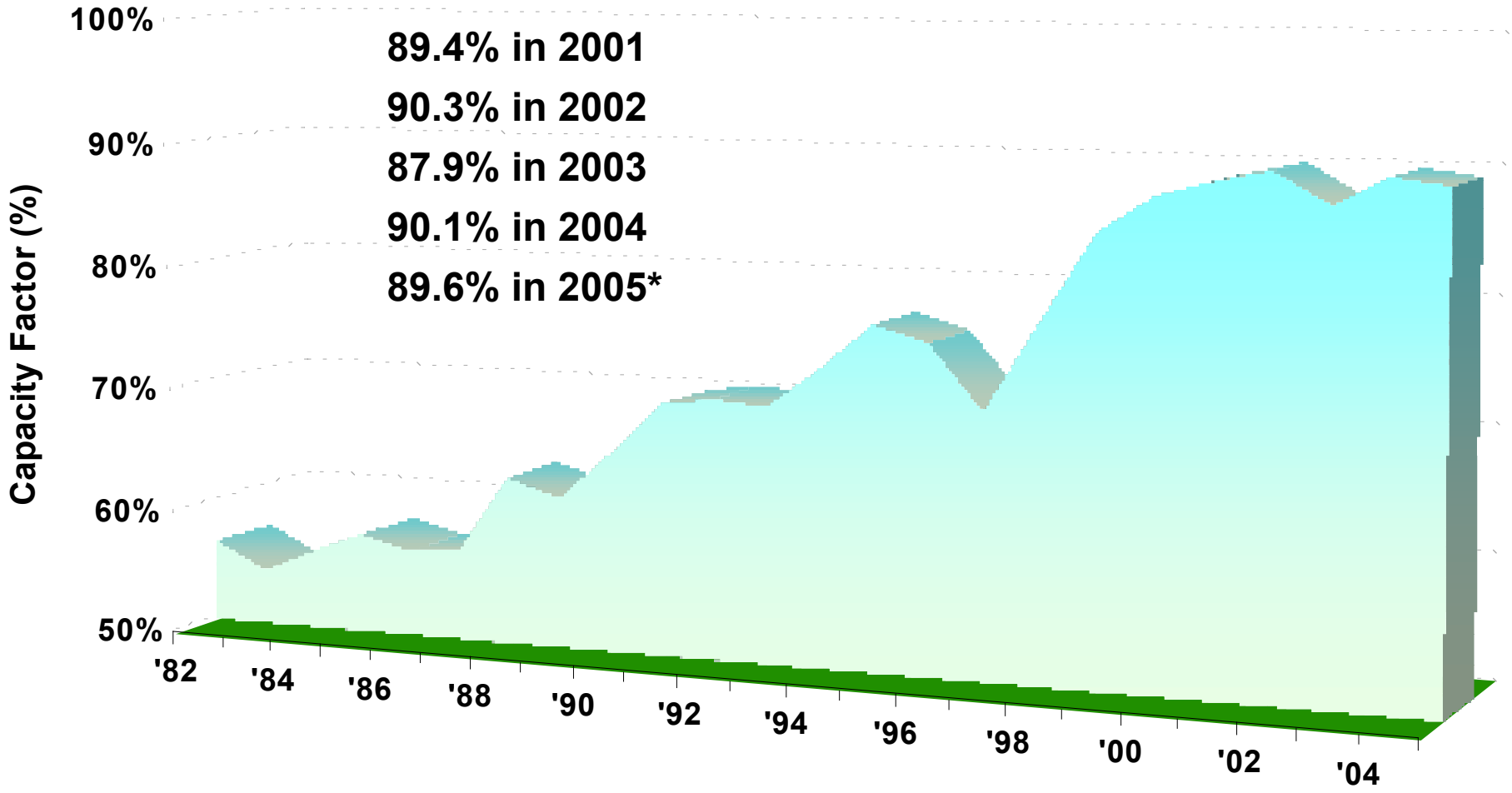
Electricity Production

Output Remains Near Record Levels



Source: Global Energy Decisions/Energy Information Administration

Industry Performance Is Consistently Excellent



**Preliminary*

Source: Energy Information Administration

What Is Driving the Interest In New Nuclear Plants?

- Increasing need for baseload generation
- Increasing environmental constraints, potential controls on carbon emissions
- Volatility in natural gas prices
- Increasing support for nuclear energy from the public and policymakers

An Emerging Consensus:

Nuclear energy key to future

CASEnergy Coalition
CLEAN AND SAFE ENERGY

"Scientific evidence shows that nuclear power is an environmentally sound and safe energy choice"

—Patrick Moore
Greenpeace Co-Founder

"Nuclear power should be an important part of [the country's energy] diversification plan."

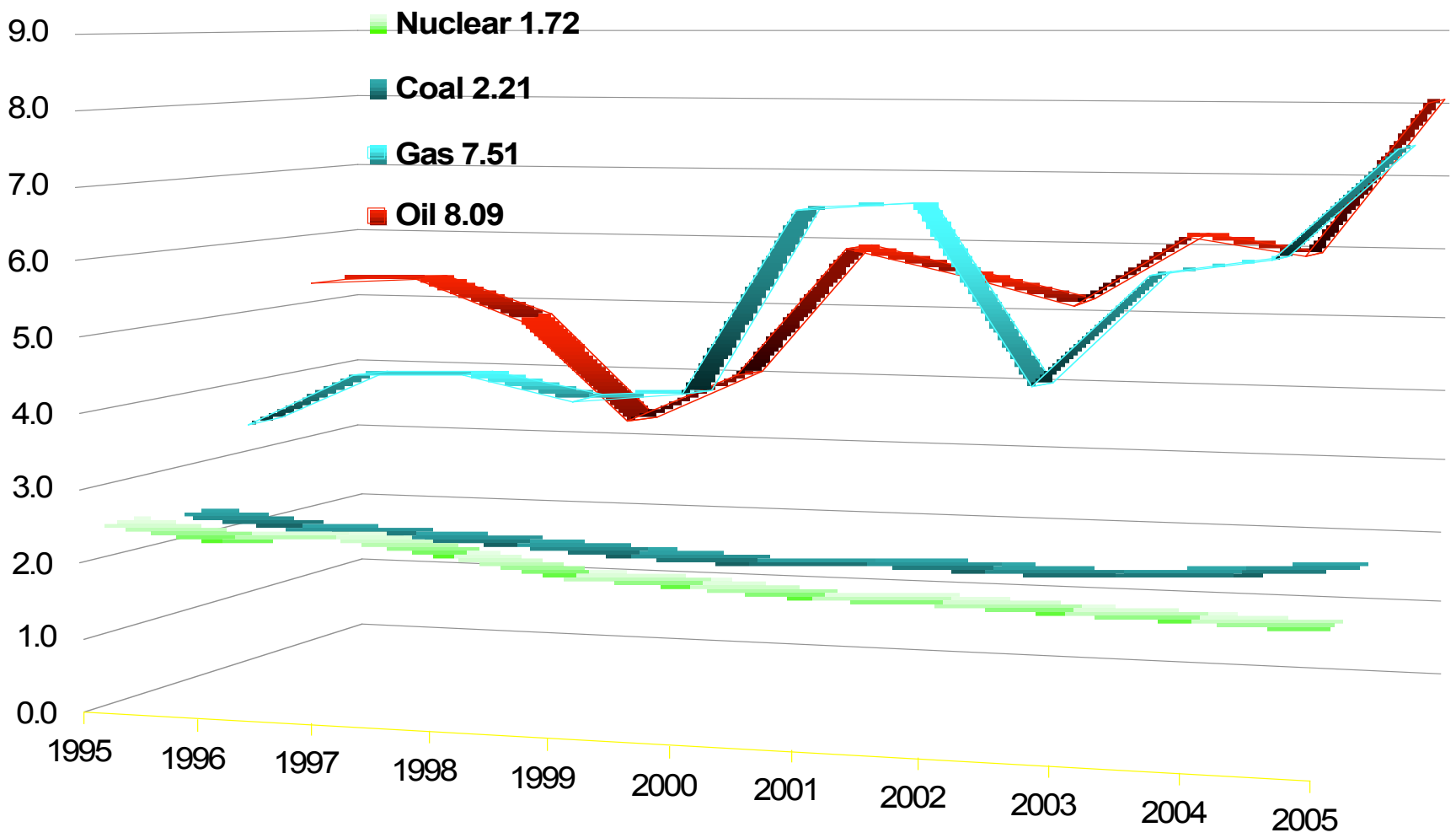
—Christine Todd Whitman
Former EPA Administrator, N.J. Gov.

www.CleanSafeEnergy.org

202.338.CASE

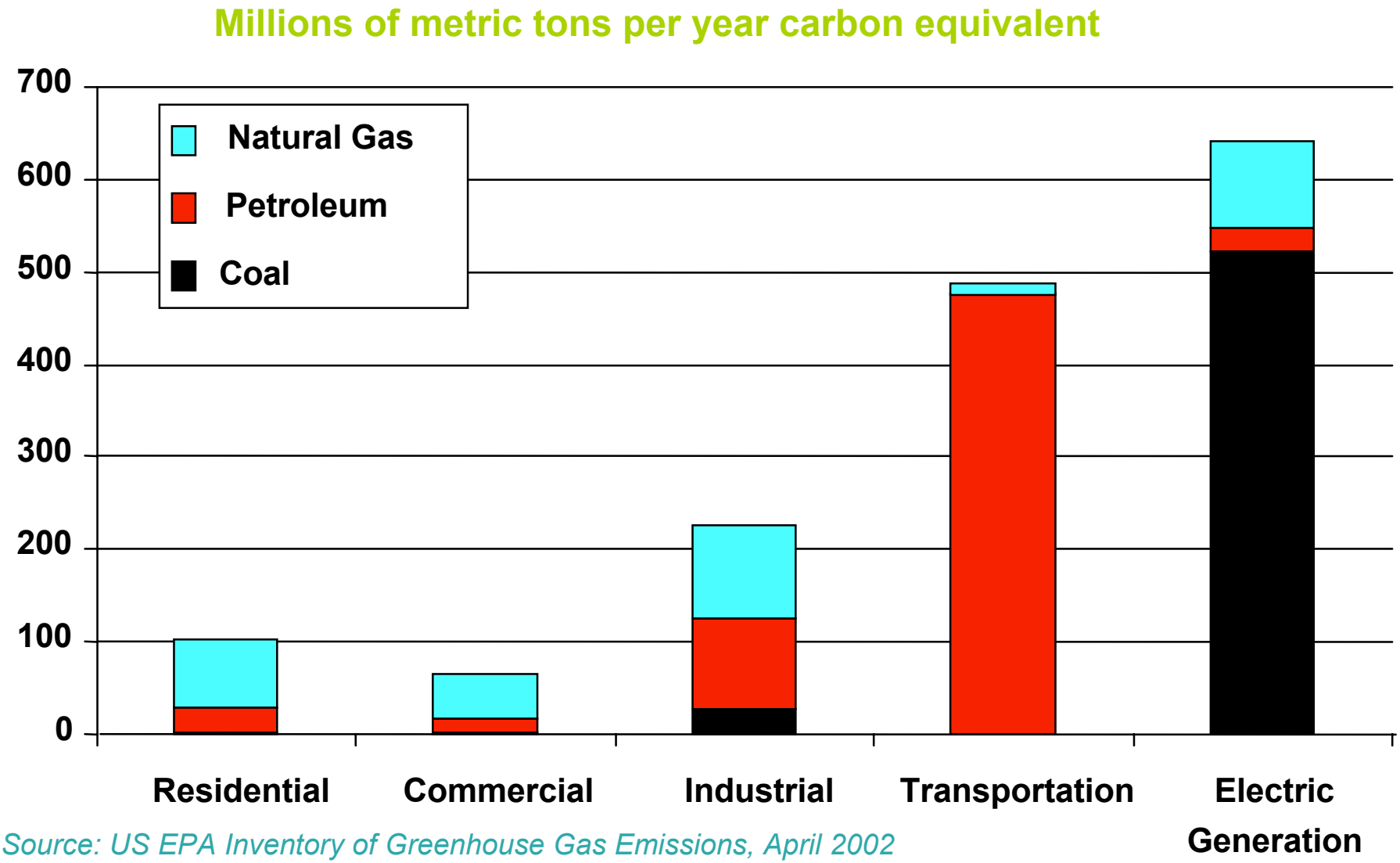
U.S. Electricity Production Costs

(in 2005 cents/kWh)



Source: Global Energy Decisions

United States CO_2 Emissions by Sector and Fuels 2000



Source: US EPA Inventory of Greenhouse Gas Emissions, April 2002

Toward New Nuclear Plant Construction

- Ensure availability of new designs to meet new capacity needs
- Resolve uncertainties in licensing, regulations and financing
- Finalize detailed design
- Rebuild human and manufacturing infrastructure

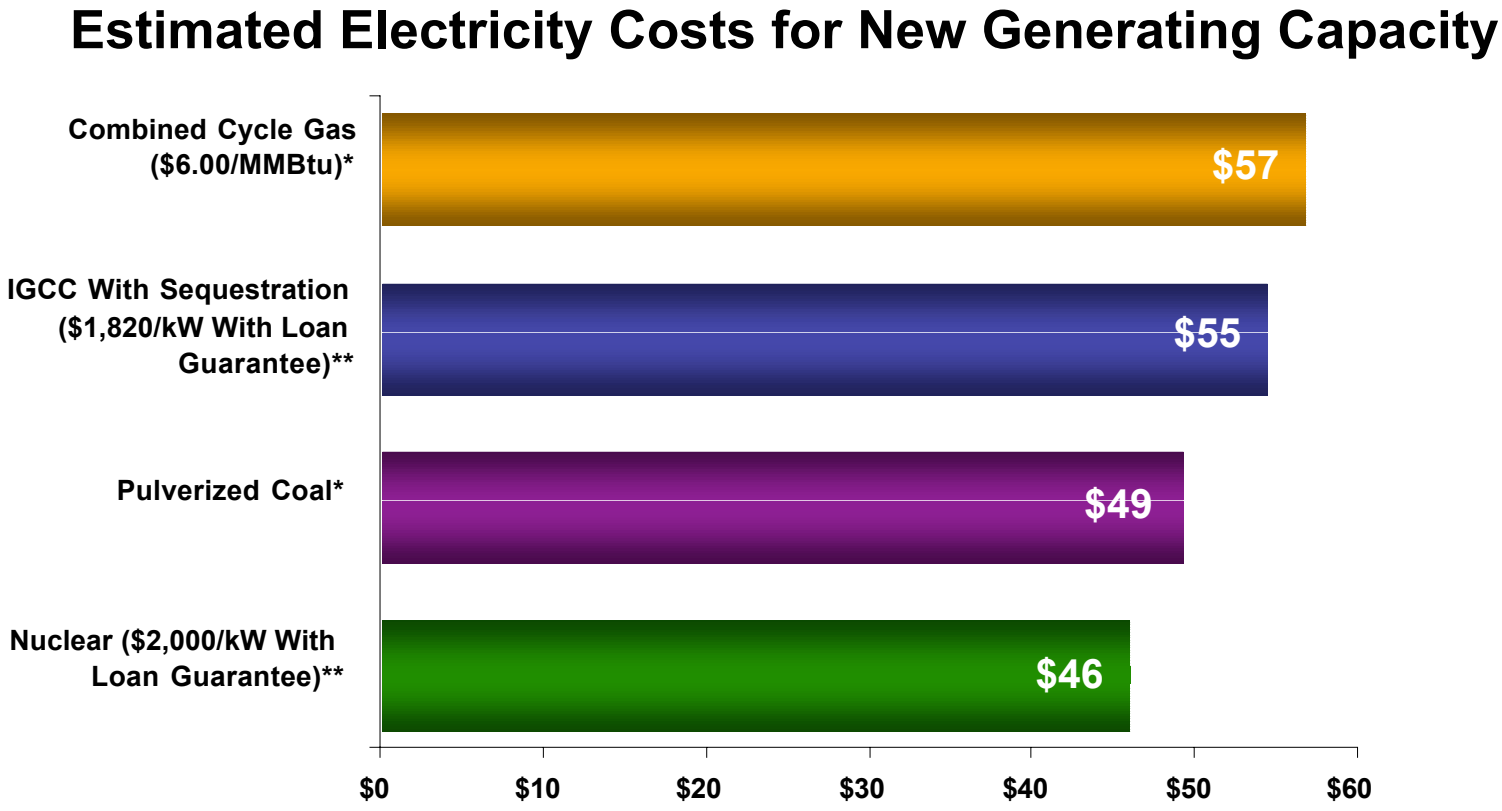
Current Environment

- Nuclear Regulatory Commission
  - Made significant modifications to improve efficiency and timing of license reviews
    - Combined construction and operating license
    - Pre-Certified Designs – safety reviews completed
    - Pre-approved sites – all environmental reviews
    - Revised regulatory oversight process – risk informed – performance based.
  - Awaiting 17 Combined Operating License applications from utilities

Congress

- Passed Energy Policy Act of 2005
  - Nuclear energy provisions
    - Production tax credit - $ 200/kw – for first movers
    - Loan guarantees
    - Insurance protection of up to $ 500 million for regulatory delays for first 2 plants.
  - Effort to stimulate orders for new plants
- Department of Energy working to develop advanced reactor designs as part of Generation IV reactors - 2030

Investment Stimulus Offsets Higher Cost of First New Plants



**Assumes 15% cost of equity, 8% cost of debt and a 50/50 debt/equity structure.*

***Assumes 15% cost of equity, 6% cost of debt and an 80/20 debt/equity structure.*

Source: NEI analysis of first-year operating costs using EIA data

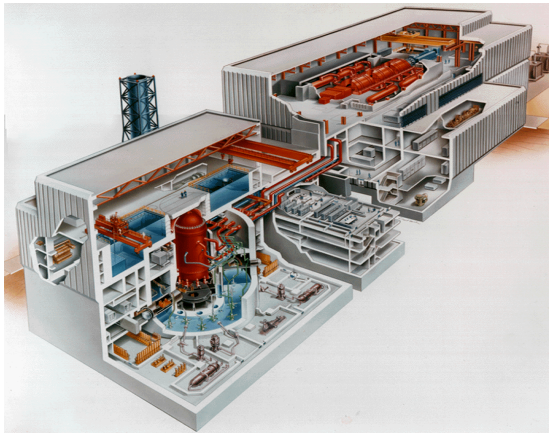
Rebuilding the Infrastructure

- Industry faces potential shortage of skilled workers
  - 50% of existing work force will retire by 2016
- Industry recruiting and training new workers
- Supply of components needed in construction
- Universities need to graduate new nuclear engineers

Industry

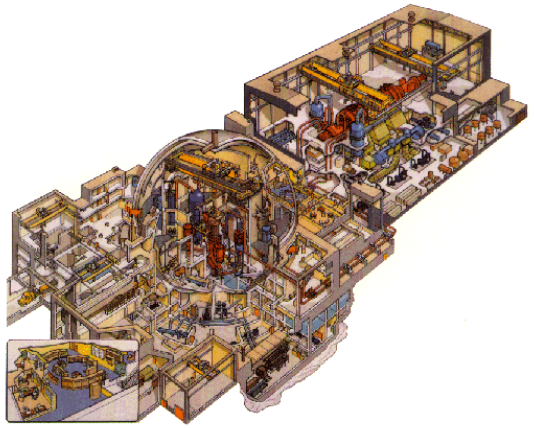
- Has 3 NRC certified designs ready for construction:
  - Westinghouse AP-600 and AP-1000 – 1000 Mwe
  - Combustion Engineering System 80+ 1200 Mwe
  - GE Advanced Boiling Water Reactor (ABWR) – 1300 Mwe
- NRC is reviewing even more designs for certification:
  - GE's ES Boiling Water Reactor (ESBWR) – 1500 Mwe
  - AREVA's – European Pressurized Water Reactor (EPR)
- NRC is also reviewing pre-applications:
  - Pebble Bed Modular Reactor – Westinghouse – 165 Mwe

New Reactor Offerings

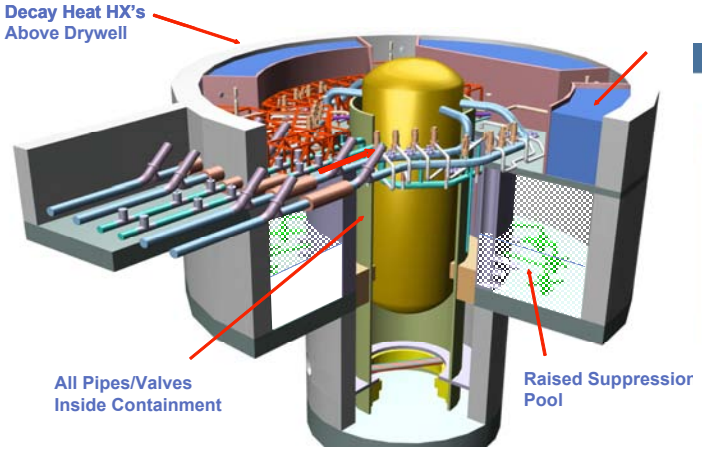


ABWR

AP-1000



System 80+



ESBWR

EPR

New Nuclear Plant Status

Company	Site(s)	Early Site Permit (ESP)	Design, # of Units	Construction / Operating License (COL)
Dominion	North Anna	Under review, approval expected 2006	ESBWR (1)	Application in 2007
TVA (NuStart)	Bellefonte	-	AP1000 (2)	Application in 2007
Entergy (NuStart)	Grand Gulf	Under review, approval expected 2007	ESBWR (1)	Application in 2007 / 2008
Entergy	River Bend	-	ESBWR (1)	Application in 2008
Southern Company	Vogtle	Under development, to be submitted 2006	AP1000 (1)	Application in 2008
Progress Energy	Florida (TBD), Harris	-	AP1000 (4)	Two applications in 2007 / 2008
SCE&G and Santee Cooper	Summer	-	AP1000 (2)	Application in 2007
Duke and Southern Company	Cherokee County, South Carolina	-	AP1000 (2)	Application in 2007
Exelon	Clinton	Under review, approval expected 2007	Not yet determined	Not yet determined
UniStar	Calvert Cliffs or Nine Mile Point	Will go to COL but submit siting information early	EPR (1)	Application in 2008 (EPR design certification conducted in parallel)
Florida Power & Light	Not yet determined	-	Not yet determined	Application in 2009
Duke	Davie County, North Carolina	Under consideration	-	-
Duke	Oconee County, South Carolina	Under consideration	-	-

Updated: 4/06

The Pump is Primed

- Utilities now working out contractual details for new orders for next series of light water reactors.
- NRC hiring staff to review applications
- Industry is hiring Nuclear Engineers to prepare for license applications and support
- New university graduates in high demand

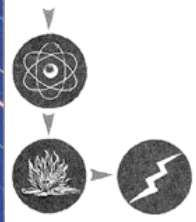
What About the Future ?

- Next Generation of New Technology
- MIT Nuclear Engineering Focus Areas
  - Advanced nuclear fuels for existing reactors
  - Advanced Reactor Concepts
    - Super Critical Carbon Dioxide
    - Super critical water
    - Fast Gas Reactors
    - Advanced Burner Reactors for waste transmutation
    - Fuel cycle studies for optimization of life cycle
    - Pebble bed reactors


MACHINE
DESIGN
SEPTEMBER 27, 2001
www.machinedesign.com
A PENTON PUBLICATION
Periodicals
USPS 881 Approved Poly
SPECIAL FOCUS
The Future of Energy
page 77
Kudos for best new designs, page 50
World's smartest appliances, page 71


Future Technology
ENERGY
Nuclear's new age
Innovative reactor concepts may help put nuclear energy back on track.
Jean M. Hoffman
Associate Editor
Fuel-element design
Fuel sphere
Half section
Coated particle
Pyrolytic carbon
Porous carbon buffer

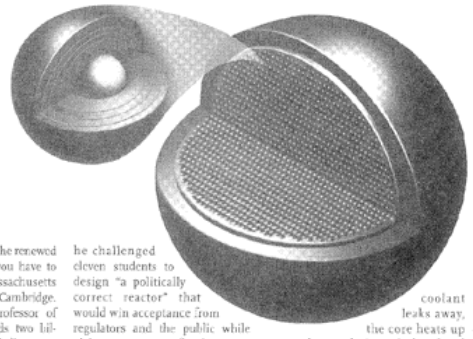

THE WORLD'S LARGEST SCIENCE & TECHNOLOGY MAGAZINE
THE WHAT'S NEW MAGAZINE
Popular Science
SPY SATELLITE SEES THROUGH CAMOUFLAGE
New Life for
Nuclear Power
Inside the Reactor That Won't Melt Down
HUNT FOR THE TOP DIGITAL CAMERA
Mystery Skin Cells
BEST HOPE FOR BURN VICTIMS
Plus
New Tech for Deep Sea Oil Drilling
www.popsci.com
Time4



The Politically Correct NUKE

MIT Students help design a nuclear power plant that they hope will revive the industry.

by Charles Wardell



To truly understand the renewed buzz for nuclear, you have to travel to the Massachusetts Institute of Technology in Cambridge. Here, Andrew Kadak, professor of nuclear engineering, holds two billiard-size balls that many believe represent the future of nuclear energy. The balls are the "pebbles" in something called a pebble bed reactor, a new type of plant that proponents say is safer and more efficient than current plants. It could even crank out electricity for less than a gas-fired plant, savings that would presumably be passed on to you. More important, considering our anxiety toward nuclear energy, it's immune to meltdowns. The technology could be implemented, possibly at Three Mile Island, within five years.

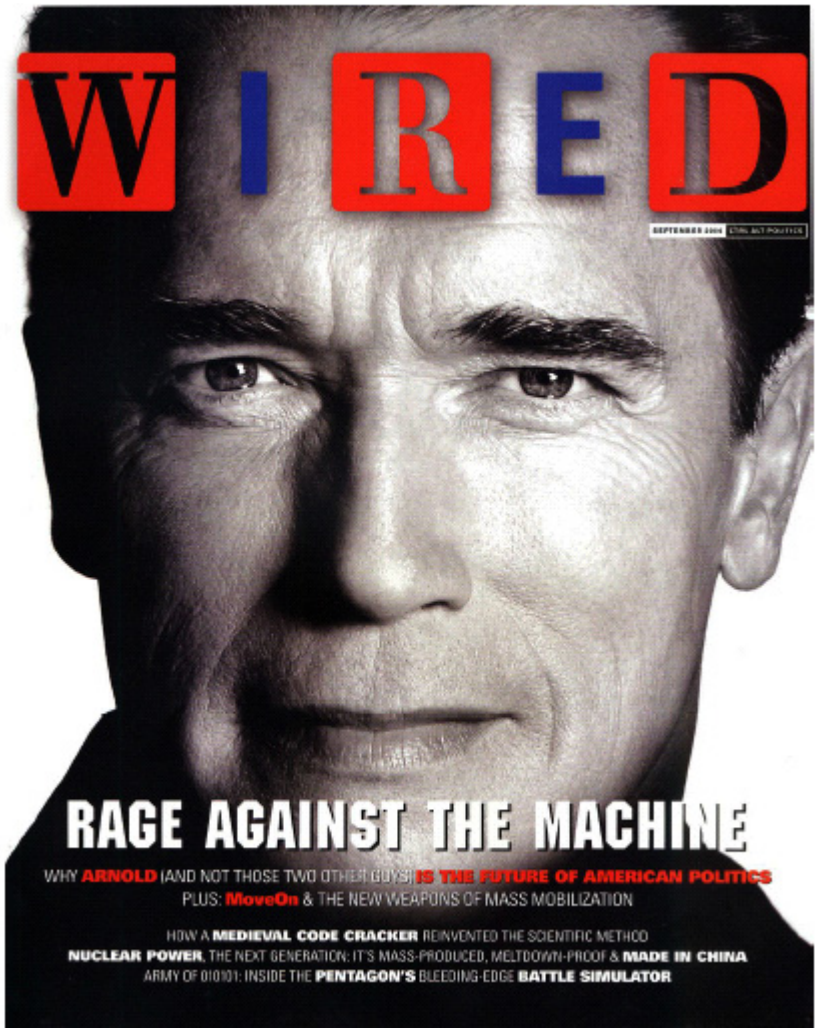
When Kadak, formerly vice president of the American Nuclear Society, came to MIT in 1997, nuclear power seemed doomed. So in January 1998, he challenged eleven students to design "a politically correct reactor" that would win acceptance from regulators and the public while giving gas a run for its energy-generating money.

All existing US commercial reactors are "light water" reactors. They're powered by half-inch cylindrical pellets of uranium—like cutoffs from a 1/2-inch dowel—stacked up in 14-foot-long metal rods. Hundreds of rods are lowered into a water-filled reactor core. The uranium atoms give off neutrons, some of which crash into other uranium atoms, splitting them, generating heat, and knocking free more atom-splitting neutrons—the process known as fission. The water in the core carries the heat away to drive an electric turbine.

Kadak's students rejected light-water technology for this reason: If the coolant leaks away, the core heats up enough to melt. Instead, they found something they considered safer: a pebble bed research reactor that had run for twenty-two years in Germany ("until Chernobyl came along and Germany got out of nuclear," Kadak says). It relied on fission too, but was fueled by eight-ball-sized pebbles, and rather than water coolant, it used helium gas.

The main safety feature is the fuel itself. Each pebble consists of roughly 10,000 "microspheres" of uranium dioxide the size of a pencil point. Each is in turn coated with several layers of graphite, and a silicon carbide outer shell. While fission heats the pebbles to as much as 1,100°C, the coatings trap all radioactivity inside. Once the

Above right: A "pebble" (about eight-ball size) containing 10,000 uranium dioxide particles the size of a pencil point, each coated with several layers of graphite and a silicon carbide outer shell (inset). Though the pebbles heat to more than 1,000°C, the coatings trap the radiation inside. The particles decay within 250,000 years, but the graphite ball maintains its integrity for more than one million years.


WIRED
RAGE AGAINST THE MACHINE
WHY ARNOLD (AND NOT THOSE TWO OTHER GUYS) IS THE FUTURE OF AMERICAN POLITICS
PLUS: MoveOn & THE NEW WEAPONS OF MASS MOBILIZATION
HOW A MEDIEVAL CODE CRACKER REINVENTED THE SCIENTIFIC METHOD
NUCLEAR POWER, THE NEXT GENERATION: IT'S MASS-PRODUCED, MELTDOWN-PROOF & MADE IN CHINA
ARMY OF 010101: INSIDE THE PENTAGON'S BLEEDING-EDGE BATTLE SIMULATOR


LET A THOUSAND REACTORS BLOOM
CHINA
Explosive growth has made the People's Republic of China the most power-hungry nation on earth. Get ready for the mass-produced, meltdown-proof future of nuclear energy.
by SPENCER REISS
Illustration by KENN BROWN and CHRIS WREN
拼裝式反應爐
Joy-Joy Snap-together Reactor
Meltdown-proof! Safe for all ages.
不會熔毀！

HTR- 10 China
First Criticality Dec.1, 2000

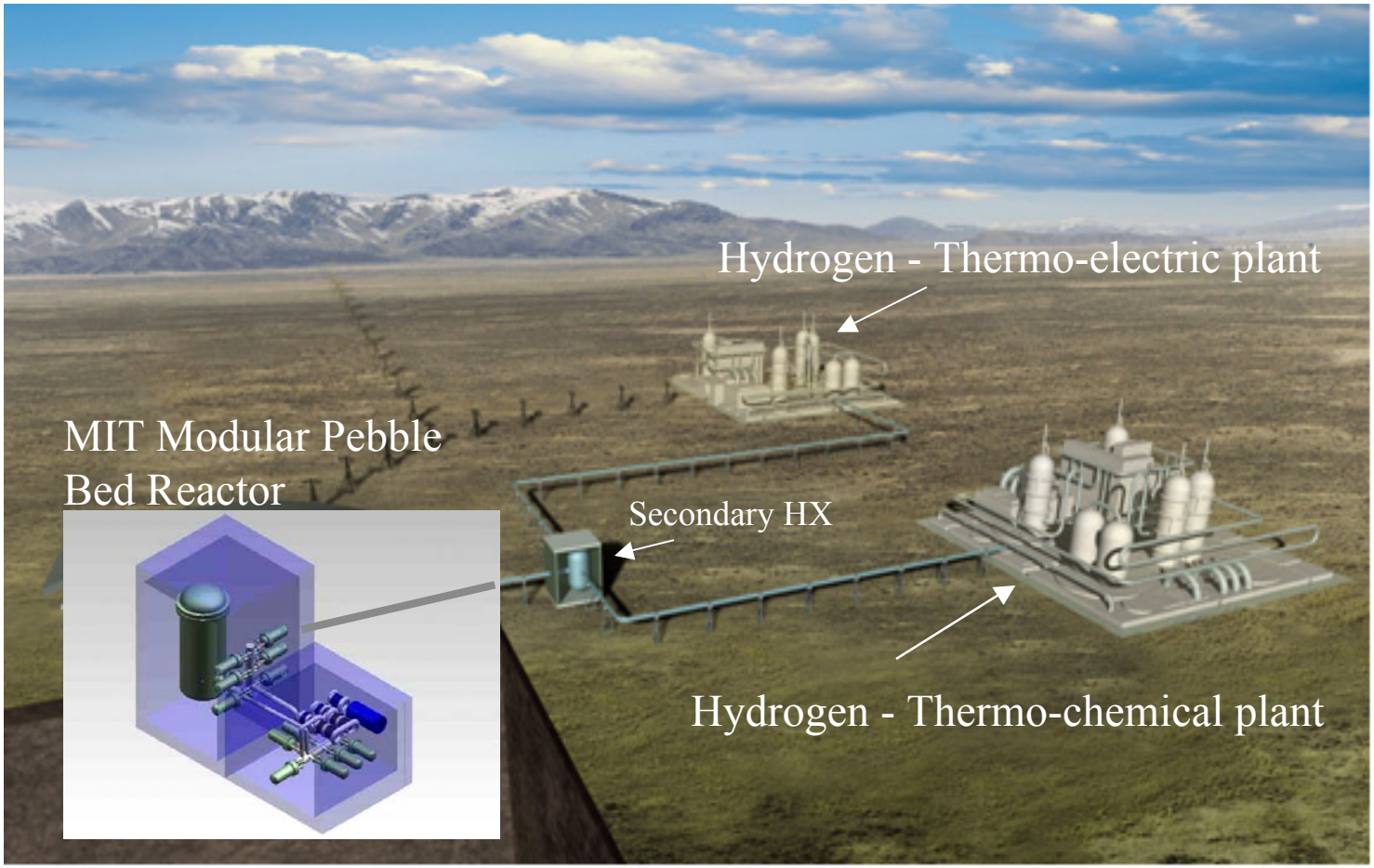
Cape Town Site of Pebble Bed Modular Reactor
165 Mwe

China - Rongcheng Site for 19 Pebble Bed Reactors for 3600 Mwe @ 190 Mwe each

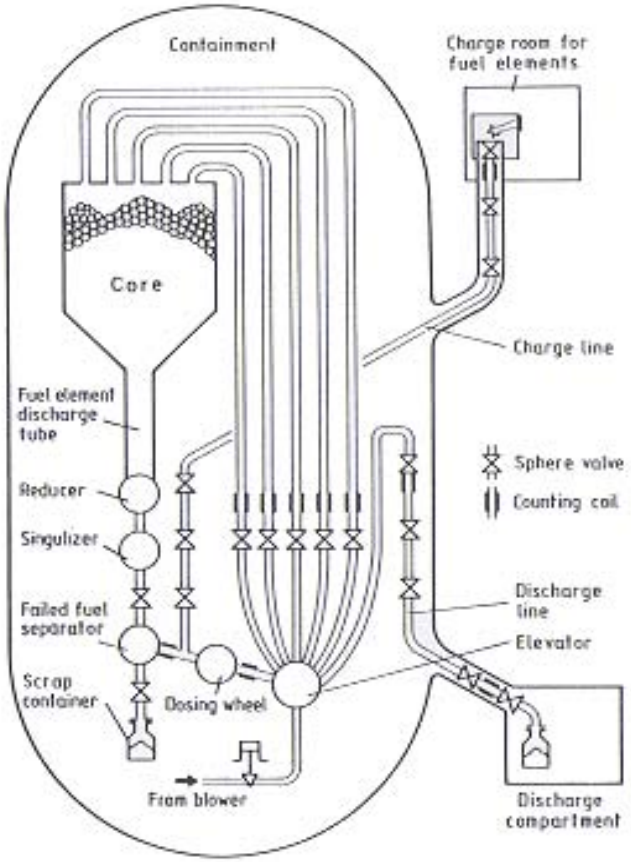
Demonstration Plant

US - Next Generation Nuclear Plant

Electricity and Hydrogen Production
2107 -2021 ?



What is a Pebble Bed Reactor ?

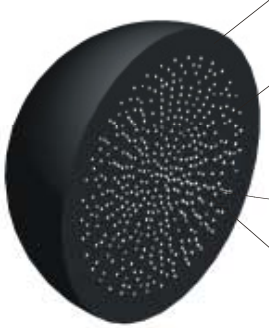


- 360,000 pebbles in core
- about 3,000 pebbles handled by FHS each day
- about 350 discarded daily
- one pebble discharged every 30 seconds
- average pebble cycles through core 10 times
- Fuel handling most maintenance-intensive part of plant

FUEL ELEMENT DESIGN FOR PBMR

Dia. 60mm

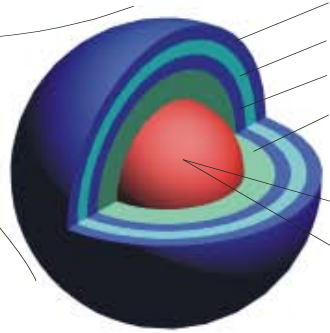
Fuel Sphere



5mm Graphite layer

Coated particles imbedded in Graphite Matrix

Half Section



Pyrolytic Carbon 40/1000mm

Silicon Carbite Barrier Coating 35/1000

Inner Pyrolytic Carbon 40/1000mm

Porous Carbon Buffer 95/1000mm

Dia. 0,92mm

Coated Particle

Dia.0,5mm

Uranium Dioxide

Fuel

Nuclear Energy for Oil Sands and Other Process Heat Applications

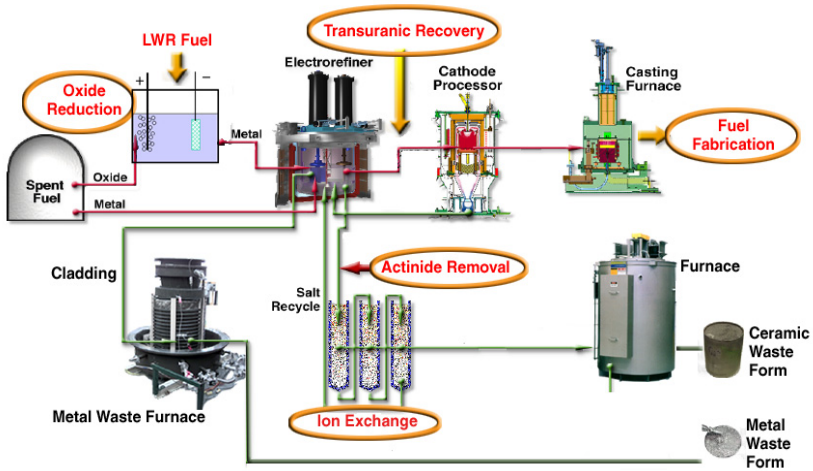
- Problem – huge CO2 emissions
- Burn Natural gas as a heat source
- Develop conceptual design of nuclear energy plant to support:
  - Extraction of oil from oil sands
  - Extraction of oil from shale
  - Enhanced oil recovery
  - Conversion of coal to gas or syncrude

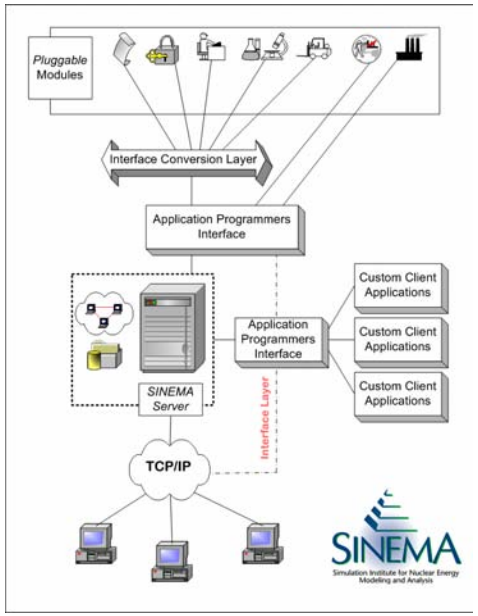
Suncor Oil Sands Operation
Alberta, Canada

Bitumen Processing Plant

Global Nuclear Energy Partnership

- Comprehensive strategy to
  - Increase U.S. and global energy security,
  - Encourage clean energy development around the world,
  - Reduce the risk of nuclear proliferation, and
  - Improve the environment

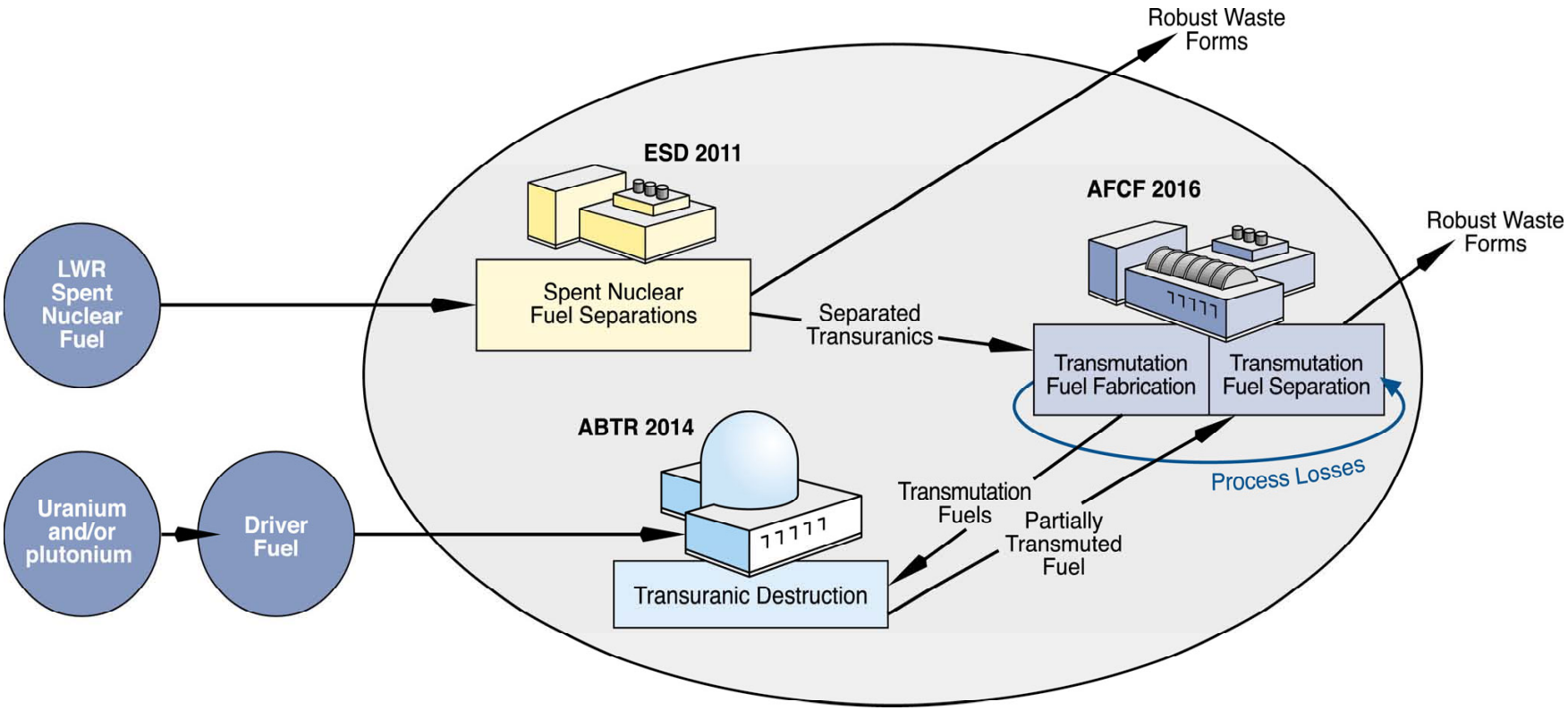




Global Nuclear Energy Partnership

- Goals of GNEP:
  - Expand domestic use of nuclear power;
  - Demonstrate more proliferation-resistant recycling;
  - Minimize nuclear waste;
  - Develop advanced burner reactors;
  - Establish reliable fuel cycle services;
  - Demonstrate small-scale reactors;
  - Develop enhanced nuclear safeguards.

GNEP-TD Facilities



No Discussion of Nuclear Energy Can Conclude without asking what Question ?

What are you going to do with the WASTE ?

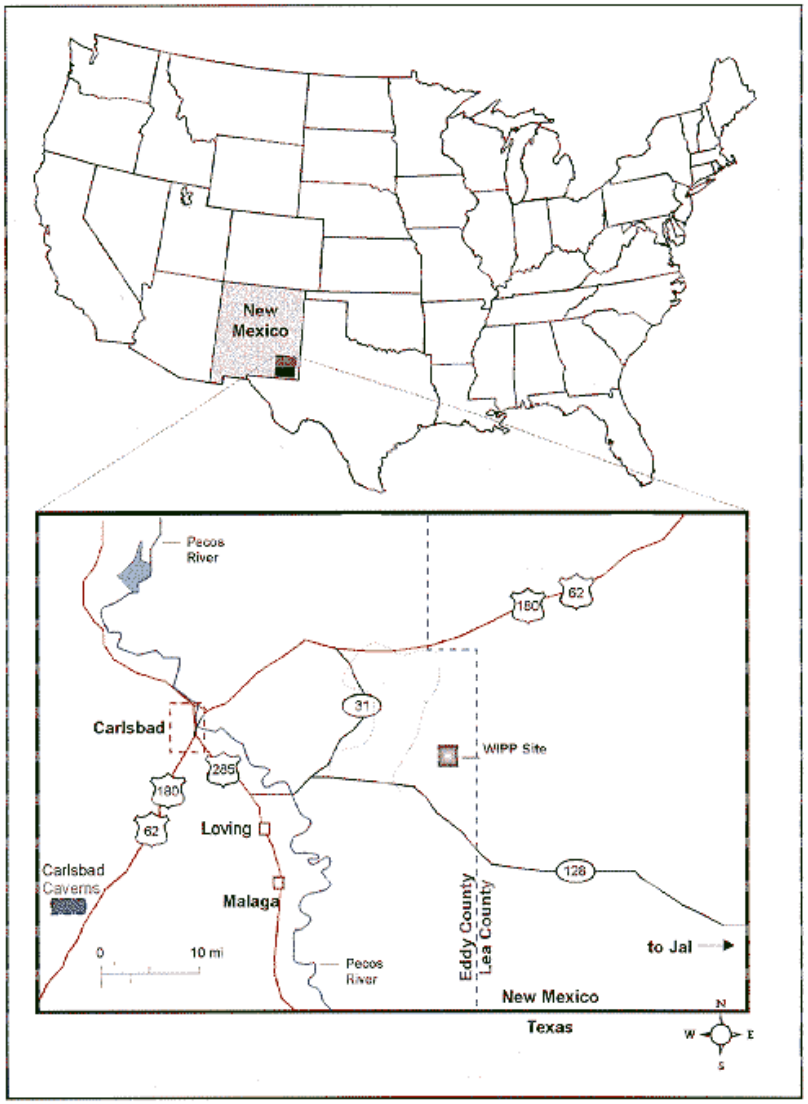
Palisades Dry Spent Fuel Storage Facility:
Seirra Nuclear Corporation Ventilated Storage Cask System

Calvert Cliffs Dry Spent Fuel Storage Facility:
VECTRA Inc., NUHOMS Concrete Storage Modules

Geological Waste Disposal

- National Academy of Science Support for Geological Disposal
- Waste Isolation Pilot Plant
- Yucca Mountain

Gabon, Africa
Site of Nature's first nuclear reactor – 3 billion years ago!

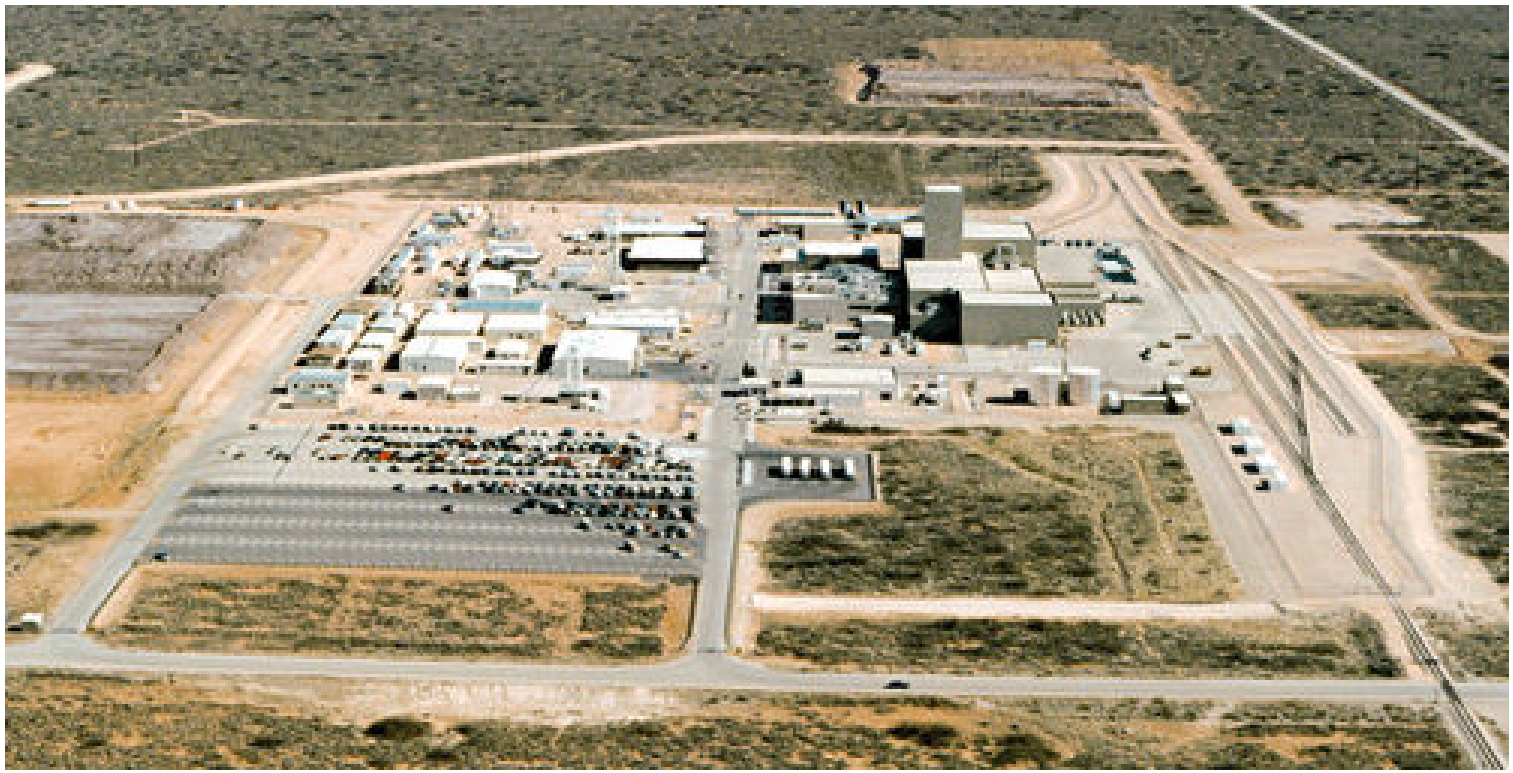


Waste Isolation Pilot Plant (WIPP)

First US Geological Repository

Carlsbad, New Mexico

Waste Isolation Pilot Plant



Excavated Salt for Geological Disposal

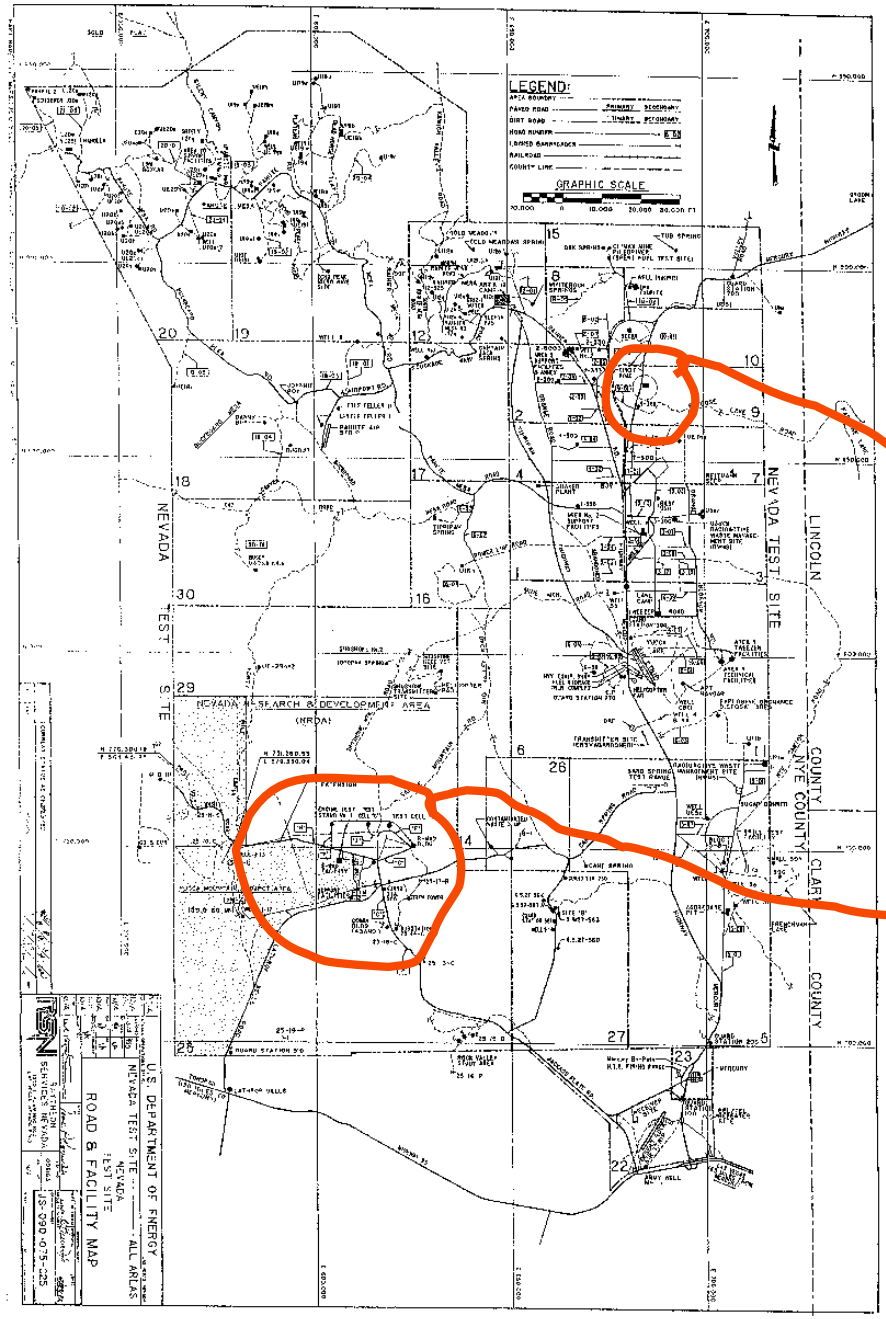
Shaft over 2000 feet in salt dome

Standing next to Plutonium disposal waste barrels

Above the WIPP Repository

Yucca Mountain Repository Program

- Nuclear Waste Policy Acts of 1982 and 1987 required operation by 1998 ……
- Present schedule is 2010 or later (2015)
- Dug 6 mile Exploratory Studies Facilities tunnel into and out of Yucca Mountain
- Spent about $8 billion to date of $16 B
- EPA sets public health standards
- NRC licenses facility



Nevada Test Site

Underground Nuclear Explosion Locations

Yucca Mountain

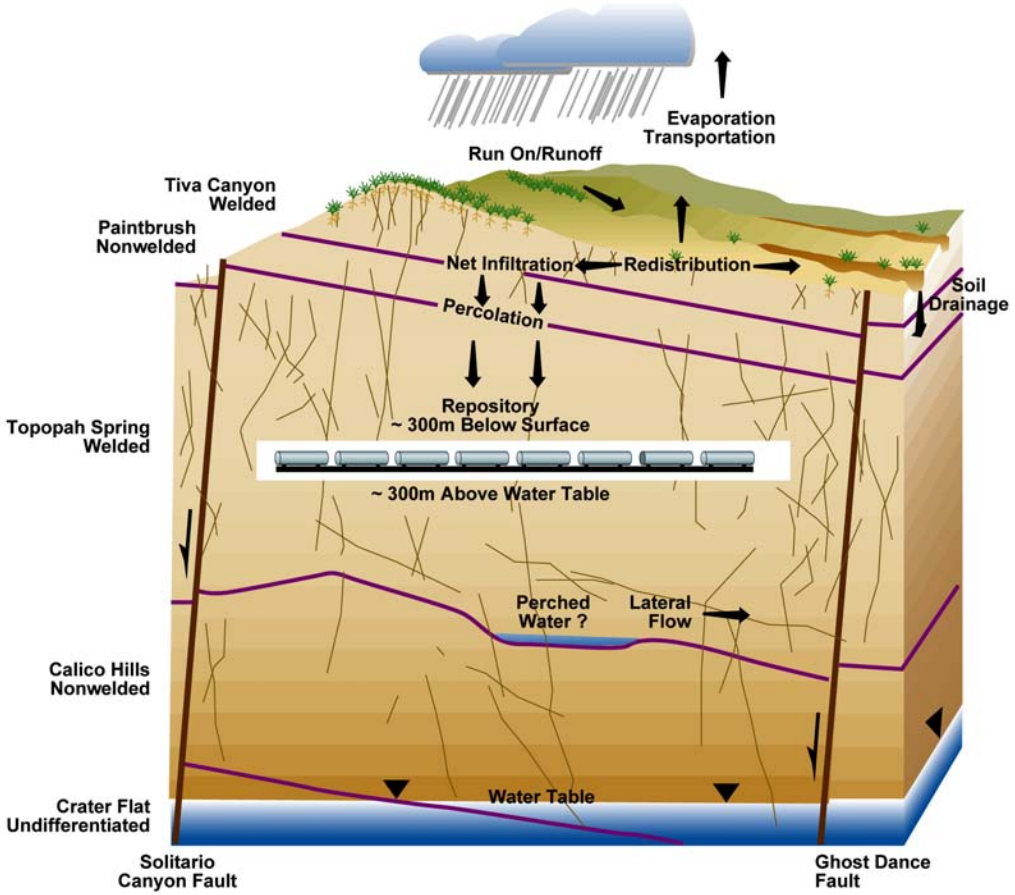
YUCCA MOUNTAIN IN THE BACKGROUND

PROPOSED STIE OF CENTRAL INTERIM STORAGE FACILITY

View from the Top of Yucca Mountain

Viability Assessment:
Total System Performance Assessment (Volume 3)

Water Movement Through the Geologic Formations



abq05c.eps

Viability Assessment:
Total System Performance Assessment (Volume 3)

Groundwater Flow Processes from the Repository Tunnels to the Accessible Environment

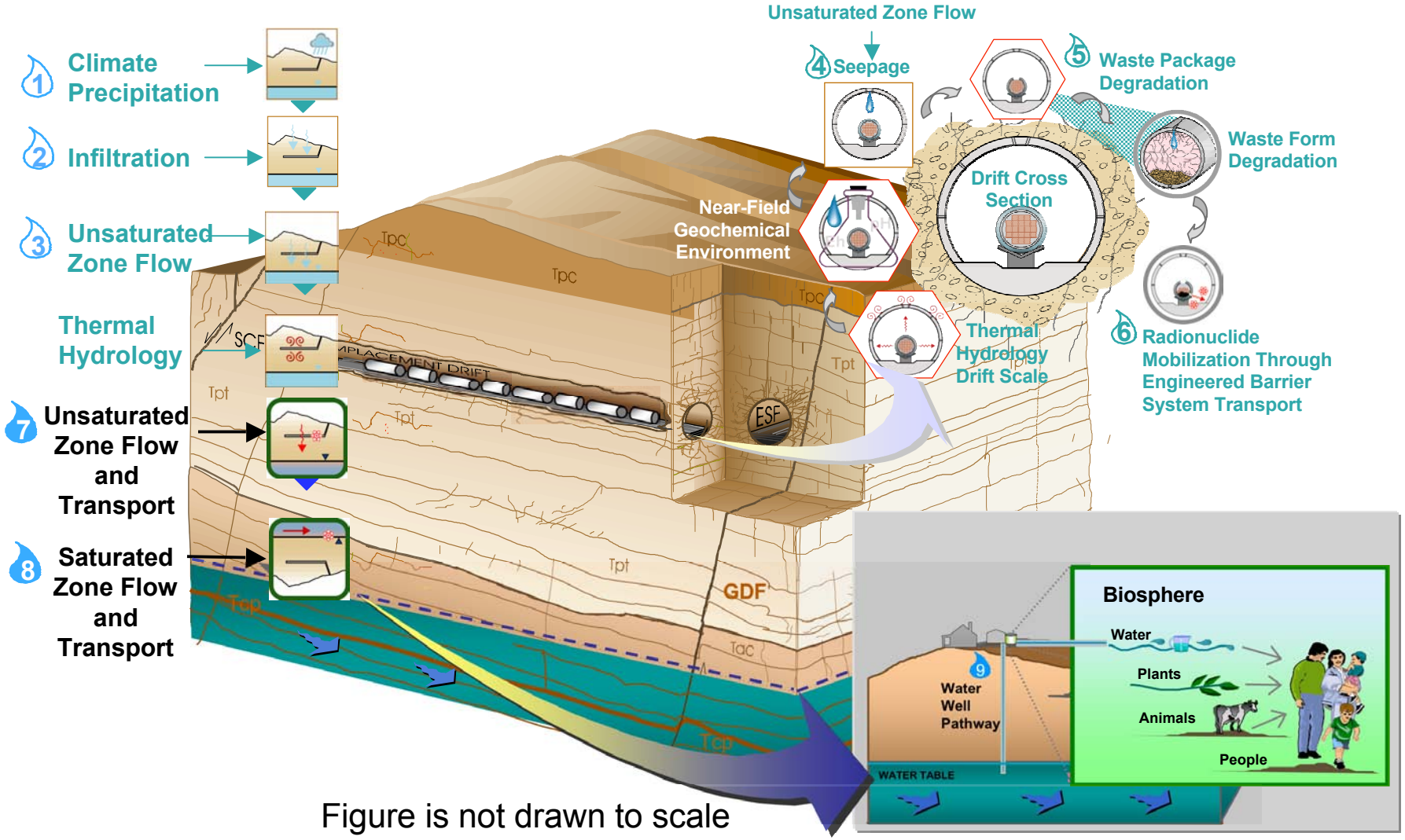


Figure is not drawn to scale

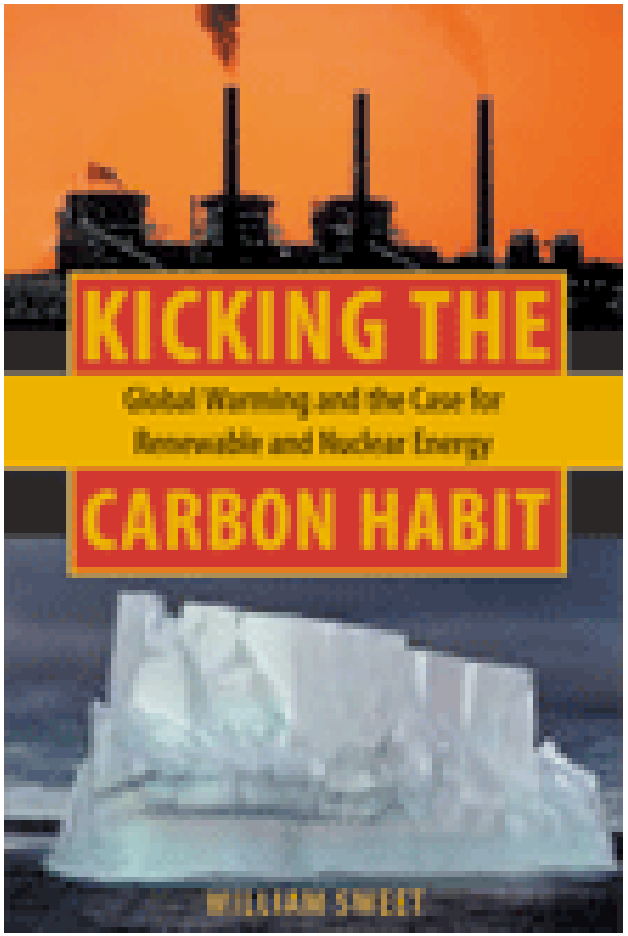
Future Challenge

- Global Warming is real

  CO2 Concentration is increasing rapidly

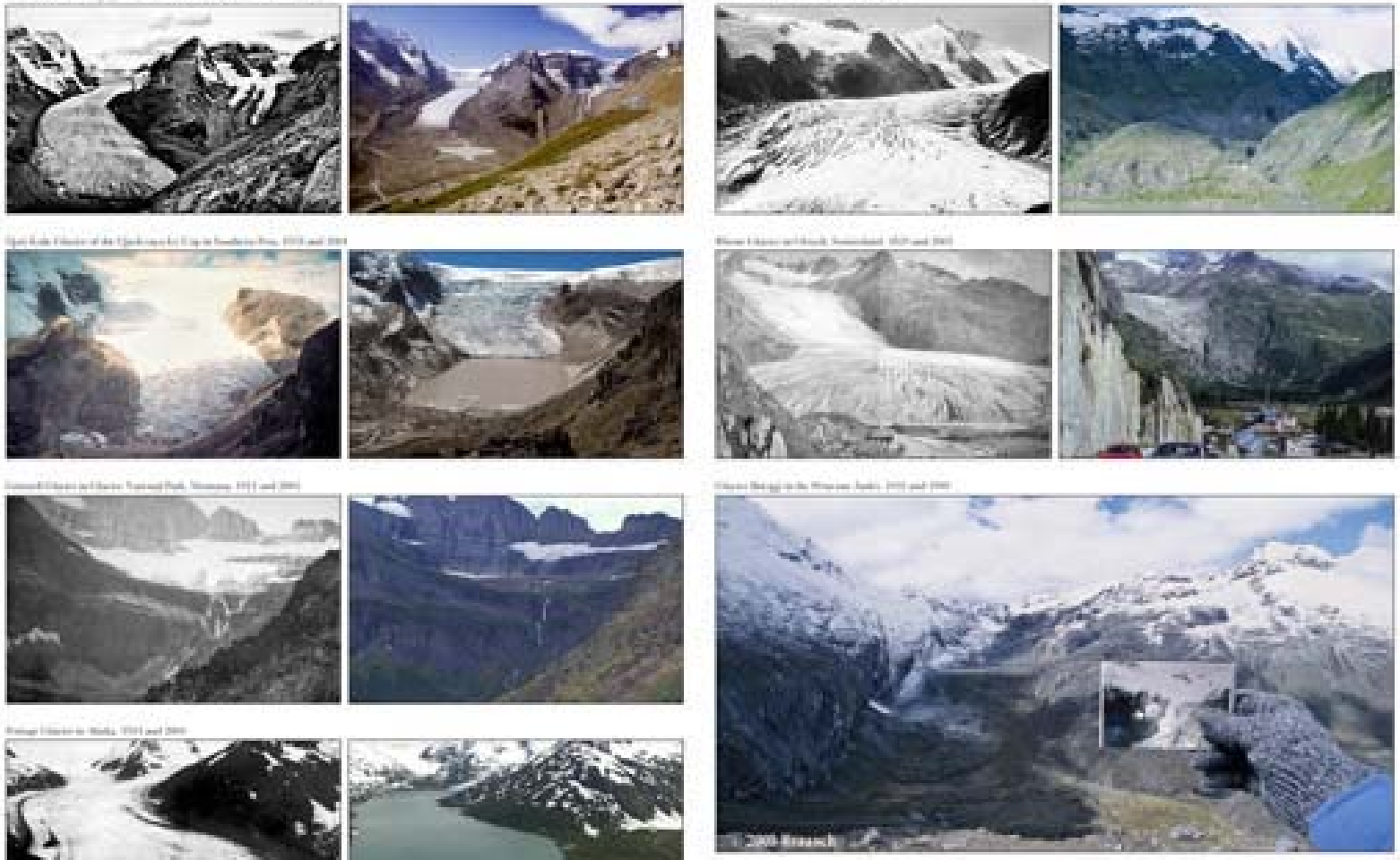
- Burning fossil fuels is harming the environment which may become “irreversible” by 2025 J. Romm.
- Nuclear can contribute to clean energy options

Clean Coal


KICKING THE
Global Warming and the Case for
Renewable and Nuclear Energy
CARBON HABIT
WILLIAM SWEET


SOCIAL SECURITY GOING BANKRUPT BY 2050 IS JUST ANOTHER HYSTERICAL SCARE TACTIC CONSERVATIVES USE WHILE THEY IGNOR MORE URGENT ISSUES LIKE....
...THE POLAR ICE CAPS MELTING IN 1000 YEARS!
EH... I'LL MOVE TO FLORIDA...
FARRINGTON ©05 DARKHORSE.

Poster of Glacier recession around the world, re-photography by Gary Braasch © 2005



Photographers' Perspectives on Global Warming

JW Gallery October 14 - November 6th
©Contemporary Glacier Photographs by Gary Braasch ©
www.globalwarmingphotographs.com

Alternative Options

Question: How many windmills at 1 Mwe each would it take to replace this nuclear generation ?

Finland Nuclear Plants
Olkiluoto

Answer: ~ 10,000

Thank you

Questions ?

Kadak@mit.edu