NUCLEAR POWER AND CLIMATE CHANGE

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PEW/NCEP 10-50 WORKSHOP

March 25-26, 2004

The Future of Nuclear Power

AN INTERDISCIPLINARY MIT STUDY

CONTEXT

"We believe that the United States will eventually join with other developed countries in the effort to reduce greenhouse gas emissions…Developing countries – certainly the large ones, such as China, India, Pakistan, Brazil and Indonesia – must ultimately be party to this effort if it is to succeed."

"There are few realistic options to reduce significantly carbon emissions in electricity generation…"

- increased efficiency
- low-carbon sources – nuclear and renewables
- large scale carbon capture and sequestration
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"…our view is that it would be a mistake to exclude at this time any of these options as a possibly important part of an overall carbon emissions management strategy."

Terawatt scale (billion kilowatts)

US total energy use : 100 Quads/year = 3 Terawatts

Note: typical large nuclear plant today is about 1000 Megawatts-electric

Time scale

- "business as usual" doubling of pre-industrial carbon dioxide concentrations at or shortly after mid-century
- energy infrastructure turn-over times; e.g., 50 years or so for large power plants

What does it take (policy, technology,…) in the next ten years to enable nuclear power to make a significant contribution (i.e. Terawatt scale) to carbon emissions management over the next half century?

- A Terawatt-electric of nuclear power globally at mid-century would likely raise the nuclear market share of electricity production only very modestly.

TECHNOLOGY PATHWAY: THERMAL REACTORS (MOSTLY LIGHT WATER REACTORS), USED PRINCIPALLY IN A ONCE-THROUGH MODE, SHOULD DOMINATE THE GLOBAL GROWTH SCENARIO TO 2050

- economics
- technical readiness/investor confidence
- nonproliferation
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Technology: modest evolution of today's reactor technology (safety features, modular construction,…)

Significant cost reduction required from historical baseline

Additional major challenges: waste management, nuclear nonproliferation, public acceptance

Pathway to a Terawatt at mid-century?

- Little new construction over the next decade
- Must establish the basis over the next ten years for ramping up to about 30/year globally
- US likely has to be a major player (from 100 reactors today to 300) if the scenario is to be realized
- Will require a new level of performance from companies, government, and international organizations

Figure 4.1 Open Fuel Cycle: Once-Through Fuel — Projected to 2050

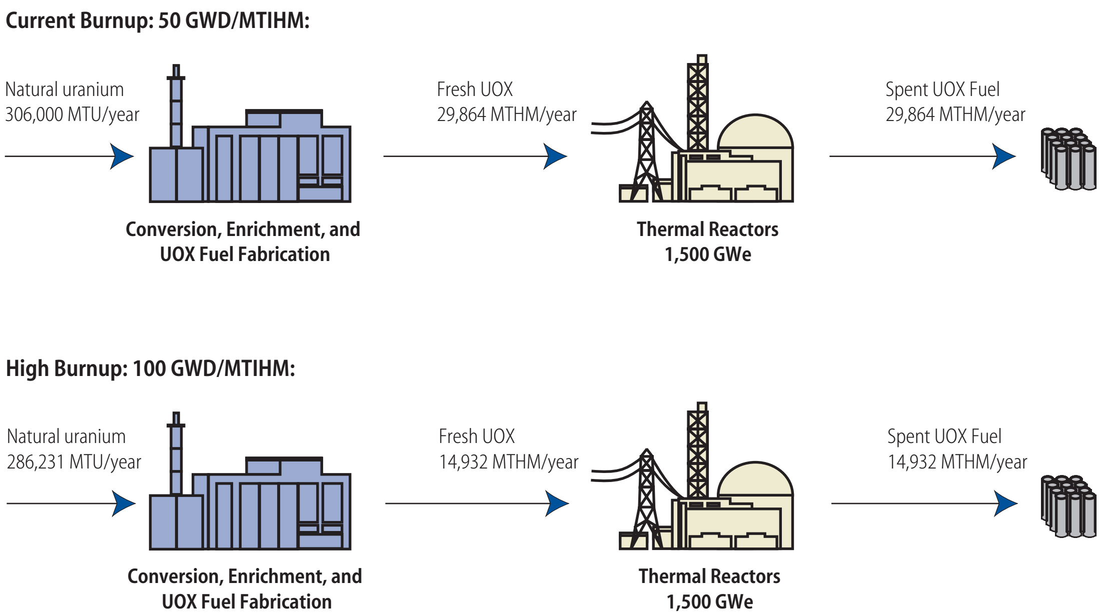
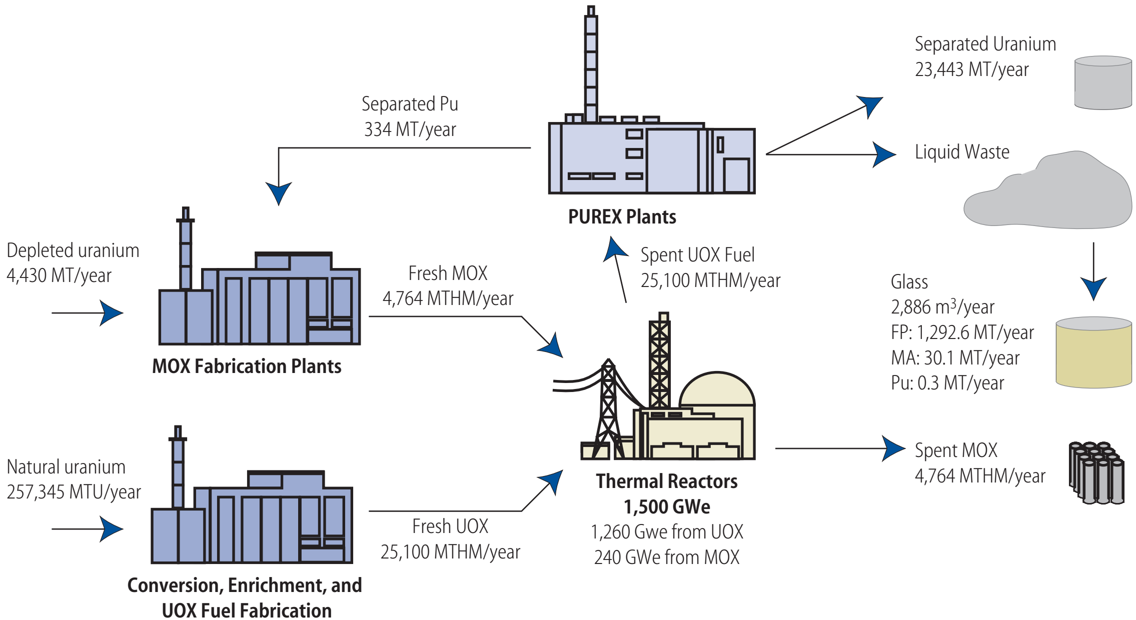


Figure 4.2 Closed Fuel Cycle: Plutonium Recycle (MOX option - one recycle) — Projected to 2050



ECONOMICS

- “axioms” for baseline cost estimates
    - merchant plant model
    - based on experience (including international) rather than engineering estimates
    - base comparisons on levelized costs

- consistent with financial market view

- also look at plausible reductions from baseline
    - competitive if capital costs reduced significantly from baseline and if risk premium worked down through success

- internalizing carbon emission “costs” significantly affects comparison with fossil plants

- public interest in resolving competitiveness issue in the context of climate change, but big “first mover” problem

Comparative Power Costs

CASE (Year 2002 $)	REAL LEVELIZED COST Cents/kWe-hr
Nuclear (LWR)	6.7
+ Reduce construction cost 25%	5.5
+ Reduce construction time 5 to 4 years	5.3
+ Further reduce O&M to 13 mills/kWe-hr	5.1
+ Reduce cost of capital to gas/coal	4.2
Pulverized Coal	4.2
CCGT[a] (low gas prices, $3.77/MCF)	3.8
CCGT (moderate gas prices, $4.42/MCF)	4.1
CCGT (high gas prices, $6.72/MCF)	5.6

a. Gas costs reflect real, levelized acquisition cost per thousand cubic feet (MCF) over the economic life of the project.

Table 5.1 Costs of Electric Generation Alternatives
Real Levelized Cents/kWe-hr (85% capacity factor)

Base Case	25-YEAR	40-YEAR
Nuclear	7.0	6.7
Coal	4.4	4.2
Gas (low)	3.8	3.8
Gas (moderate)	4.1	4.1
Gas (high)	5.3	5.6
Gas (high) Advanced	4.9	5.1
Reduce Nuclear Costs Cases		
Reduce construction costs (25%).	5.8	5.5
Reduce construction time by 12 months	5.6	5.3
Reduce cost of capital to be equivalent to coal and gas	4.7	4.4

Carbon Tax Cases (25/40 year)

	$50/tC	$100/tC	$200/tC
Coal	5.6/5.4	6.8/6.6	9.2/9.0
Gas (low)	4.3/4.3	4.9/4.8	5.9/5.9
Gas (moderate)	4.6/4.7	5.1/5.2	6.2/6.2
Gas (high)	5.8/6.1	6.4/6.7	7.4/7.7
Gas (high) advanced	5.3/5.6	5.8/6.0	6.7/7.0

PRODUCTION TAX CREDIT FOR FIRST MOVERS

E.G., 1.8 cents/kWh-e [corresponds to $70/tonne avoided carbon from coal]

- up to $200/kW-e [scale of first mover costs]
- up to 10 GW-e
- full credit realizable in principle in 1.5 years of operation
- public benefit of avoided carbon for 40-60 years

- incentive to complete plant at lowest cost and shortest schedule, and to operate efficiently
  - keep risk with industry
  - demonstrate cost structure to industry and investors

- technology-neutral carbon-free incentive?
  - Wind already has 1.8 cents/kWh-e for 10 years
  - Solar, nuclear, coal+sequestration,…
  - Total credit available different for baseload technologies

- 2003 energy bill conference report/Section 1310
  - 6 GW-e, allocated by Secretary
  - up to $125/kW-e per year (80% capacity factor)
  - 8 year period

TECHNOLOGY-NEUTRAL CARBON-FREE STANDARDS?

- "renewable" portfolio standards?
- Clean Development Mechanism?
- …

ADDITIONAL VIEWS SUBMITTED FOR THIS PANEL

Industry view – Marilyn Kray (Exelon)

Principal criteria for new nuclear plant decision

- operational confidence based on familiarity with system design and standardization of both design and operation
- licenseability, for which extensive regulatory history with light water reactors is very important
- economics, requiring large reductions in overnight capital costs comparted to past experience

Other criteria in business decision:

- reliable demand for baseload electricity
- cost of alternatives, especially natural gas prices
- continued successful operation of existing nuclear plants and a path to resolve plant security and spent fuel disposal issues
- regulatory predictability through the Construction and Operating License process
- possible risk sharing through a "first mover consortium"
- recognition of the environmental benefits

Environmental organization view – Tom Cochran (NRDC)

- argues against subsidy of first mover nuclear plant construction

NONPROLIFERATION TREATY/ATOMS FOR PEACE FRAMEWORK

- needs strengthening for growth scenario (e.g., Iran situation)
- need evolved framework that is politically non-discriminatory but risk-based
- risk: power reactors are NOT per se the proliferation risk; supporting technologies (enrichment, spent fuel reprocessing,…) ARE
- possible approach: "privileged" and "fuel cycle" states
    - "privileged states" have assistance, as desired, with power reactor design, construction, and operation/training, but not with fuel cycle facilities
    - they have international guarantees on fresh fuel supply and spent fuel removal for the life of the reactors – NO WASTE PROBLEM
        - e.g., US-Russia-Iran discussions of last 5 years
    - avoid intrusive heightened international safeguards/inspection framework required of new fuel cycle facilities
    - avoid costs of building large nuclear infrastructure
    - manageable even with possible global closed fuel cycle
    - "fuel cycle states" subject to new level of safeguards and security requirements and are responsible for spent fuel disposition or reprocessing – INTERNATIONAL SPENT FUEL DISPOSITION
    - all subject to Additional Protocol and strengthened sanctions regime
- a technology- and risk-based approach in spirit of NPT Article IV
- VERY challenging

PUREX/MOX – "CLOSED" FUEL CYCLE

- Not enough uranium? - NO

- Energy value of Plutonium? - NOT ECONOMIC

- Help resolve long term waste management challenge? - YES, BUT…

    - Scientific basis of long term geologic isolation appears sound (but need to demonstrate implementation)

    - Mass and volume reduction are not terribly important for repository design; heat and radioactivity reduced only marginally through recycle and dominate on the century time scale

    - Issue is human health, so need to trade long term benefit against short term increases in waste streams, exposures, and safety issues

    - Public perception is important but little evidence that public is more concerned about millennium time scale than generational time scale

    - Other approaches may yield even greater benefits more simply and economically

        - E.g., advanced engineered barriers, deep borehole disposal,…

DEEP BOREHOLES

Deep holes bored into stable crystalline rock

- stable pre-Cambrian continental cratons
- also Palezoic and Mesozoic
- use about 2 to 5 km depth
- established drilling technology, including multiple boreholes from one surface rig, plus promising new technologies leading to linear cost
- extensive downhole instrumentations (porosity, permeability, saturation, temperature, pressure, chemical composition, pH, oxygen/reduction potential, …)

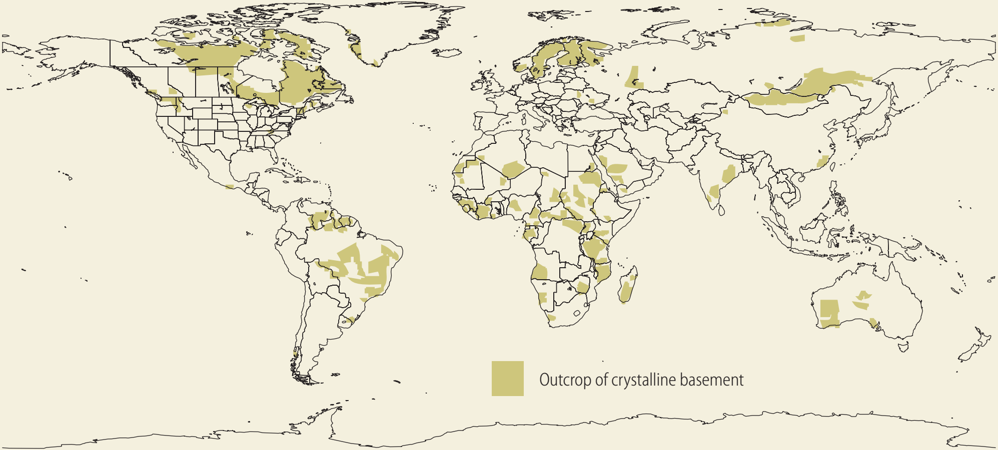
Attributes/guidelines for isolation from biosphere for million year time scale (Heiken, LANL)

- very low permeability
- reducing environment
- not subject to surface vagaries
-
-
- emplacement/plug technology

Candidate formations generally well distributed globally (Heiken)

Retrievability?

Figure A-7.D.1 Distribution of Crystalline Basement Rock Exposed to the Surface

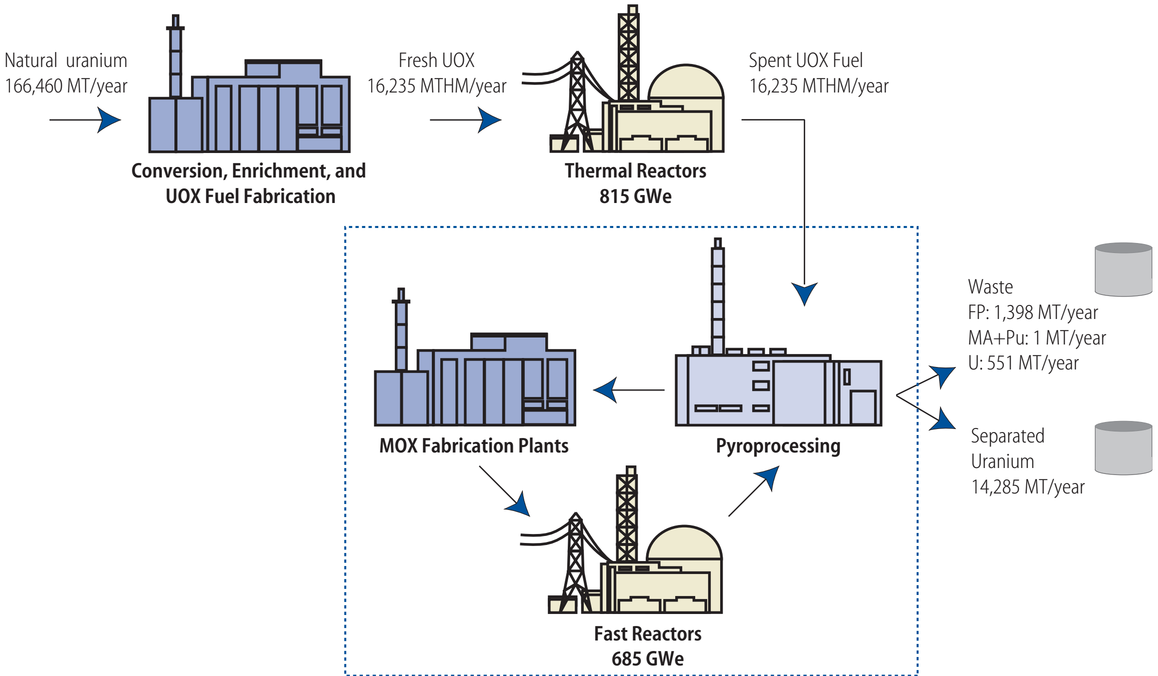


Prepared by Grant Heiken, Los Alamos Scientific Laboratory, Earth and Environmental Sciences Division

RESEARCH AND DEVELOPMENT

- R&D program should have a strong focus on support of the science and technology pathways that address the central issue: enabling the option of major global expansion of nuclear power over the next 50 years with increased safety, better economics, accepted waste management, and improved proliferation-resistance
    - This time scale is crucial if nuclear power is to be a significant contributor to meeting a three-fold increase in electricity demand without exacerbating climate change concerns
    - Uranium resource base, waste management,…
- if nuclear power continues to grow dramatically beyond mid-century, advanced closed fuel cycles will eventually be needed, but still need to overcome major technical obstacles for economic commercial-scale activity
    - support aggressive R&D on advanced closed fuel cycles and associated reactors for the very long term, but
        - no separated Pu in normal operation
        - early focus on analysis, simulation tool development, basic science and engineering of advanced concepts, appropriate scale projects
        - large demonstration projects should wait until better analysis tools are available and the "technology space" has been more thoroughly explored
        - international fuel cycle work should be jointly managed by Nuclear Energy and Nuclear Nonproliferation offices
- Tom Cochran (NRDC)
    - Raises issue of proliferation risk inherent in pursuing international fuel cycle R&D
    - Needs to be balanced against benefits of engagement in broader nonproliferation context, including shaping direction and management of program for "proliferation-resistance"
        - E.g., focus on analysis, simulation and basic research; management role for nonproliferation offices

Figure 4.3 Closed Fuel Cycle: Full Actinide Recycle — Projected to 2050



EDITORIAL – SCIENCE MAGAZINE (23 JANUARY 2004)

Richard Meserve, Carnegie Institution of Washington

EXCERPTS

A recent MIT study on the future of nuclear power argues that nuclear power should be maintained as an energy option because it is an important carbon-free source of power…the study also observes, based on a survey of adults in the United States, that those who are very concerned about global warming are no more likely to support nuclear power than those who are not.

Unfortunately, two institutions that might be expected to explain the facts are largely silent on this issue. Environmental groups include a large and dedicated antinuclear constituency, so even environmentalists who might give nuclear a second look might hesitate to embrace that view publicly. The nuclear industry is reluctant to advance the case because generating companies also rely on fossil-fuel plants (primarily using carbon-intensive coal)…

As for the Bush Administration, it has aggressively supported nuclear power but has carefully avoided emphasizing the link…reflects the hesitancy that has characterized the Administration'\s approach to the global warming issue.

…the harsh reality is that any serious program to address global warming cannot afford to jettison any technology prematurely.

…scientific and educational community should seek to ensure that the public understands the central link between nuclear power and climate change.

ACTIONS IN 10 FOR IMPACT IN 50:

- FIRST MOVER PRODUCTION TAX CREDITS

- “TECHNOLOGY NEUTRAL” STANDARDS (RPS, CDM,…)

- R&D FOCUSED ON VIABLE TECHNOLOGY PATHWAY (URANIUM RESOURCE EVALUATION, WASTE MANAGEMENT, GAS REACTORS,…)

- INITIATE MODERNIZATION OF NONPROLIFERATION IMPLEMENTATION REGIME (ADDITIONAL PROTOCOL, LEASING OF NUCLEAR FUEL, ADVANCED FUEL CYCLE R&D WITH STRINGENT MANAGEMENT CONSTRAINTS,…)

- PUBLIC EDUCATION ON GHG-ENERGY CONNECTION