Northwest Power and Conservation Council

January 30, 2007

MEMORANDUM

TO: Power Committee

FROM: Jeff King

SUBJECT: Briefing regarding the cost and prospects for new nuclear power plants

Jim Harding of Harding Consulting will brief the Power Committee on the findings of his recent assessment of the costs and prospects for new nuclear power plants.

High natural gas prices, increasing concern regarding global climate change and Energy Policy Act incentives are motivating developers to seriously consider construction of new nuclear capacity in the United States. The Nuclear Regulatory Commission has received 17 Letters of Intent to Apply for a Major License Application, some for dual units. While it is unlikely that all of the notices will mature into active projects, it is expected that several will proceed.

None of the NRC notices of intent are for western sites and it is unlikely that a decision to develop new commercial nuclear unit in the Northwest would be made prior to successful operation of a new plant elsewhere. This is not likely prior to 2015. However, the Energy Policy Act of 2005 does authorize development of a demonstration nuclear combined power and hydrogen production plant (Next Generation Nuclear Plant) at Idaho National Laboratory at Idaho Falls. The target completion date for this plant is 2021 and several Northwest utilities are including nuclear power in their IRPs for this time period. Because of these developments, it is important that the Council be cognizant of the status of nuclear generating technologies. Mr. Harding's recently completed assessment provides an opportunity for the Council to secure current information regarding proposed commercial nuclear technology.

q:\tm\council mtgs\feb 07\(p4-1) harding nuclear.doc

851 S.W. Sixth Avenue, Suite 1100
Portland, Oregon 97204-1348
www.nwcouncil.org

Steve Crow
Executive Director

503-222-5161
800-452-5161
Fax: 503-820-2370

Costs and Prospects for New Nuclear Reactors

Jim Harding

February 2007

Presentation to NW Power Council

Current Status in the US

- About 100 GW of nuclear capacity (20% of electric supply), with 14-30 units under active consideration, mainly in Texas and the Southeast, plus 3.2 GW in upgrades
- 27 units under way worldwide totaling about 22 GW
- Upgrades and life extension generally economic for the existing fleet, driven by
  - Substantial improvement in capacity factors
  - High gas prices
  - Reasonably stable operations and maintenance costs
  - Ownership consolidation

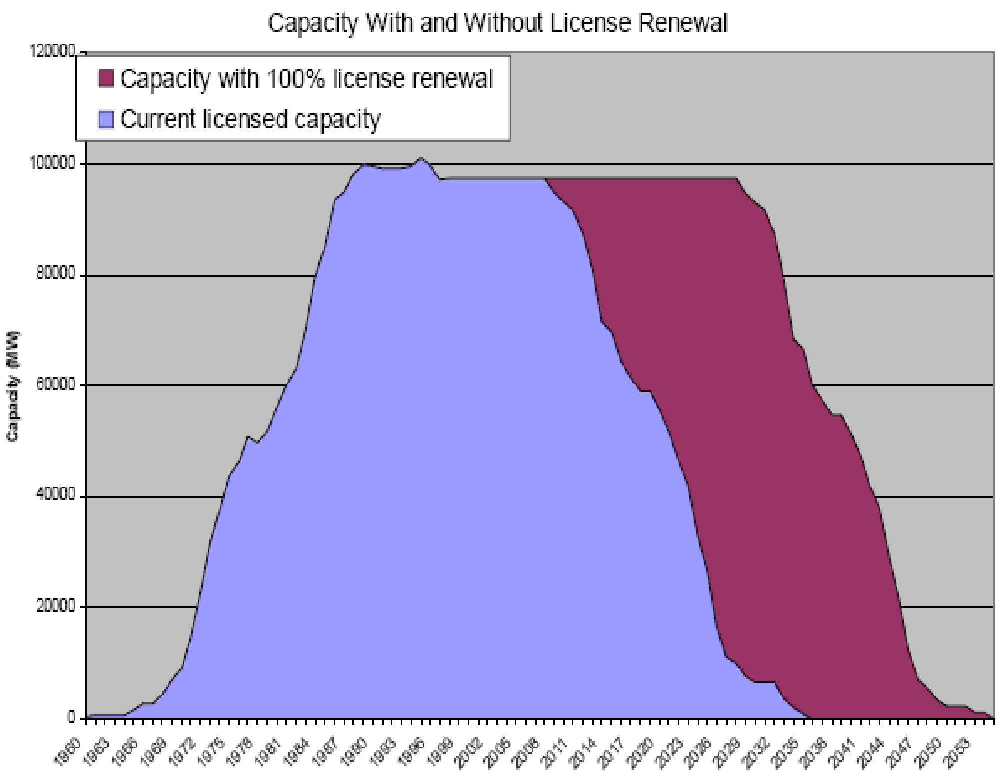
New Reactor Environment Uncertain

- NEPAct 2005 incentives (Production Tax Credit, loan guarantees, delay insurance) all significant, but somewhat uncertain near and long term
- Rapid recent real construction cost escalation
- Yucca Mountain delays and problems, e.g. at statutory volume limit
- Uranium and enrichment cost and supply challenges
- Questionable long term viability of streamlined licensing process
- Regulatory treatment – e.g., construction cost cap

Some Noticeable Improvements

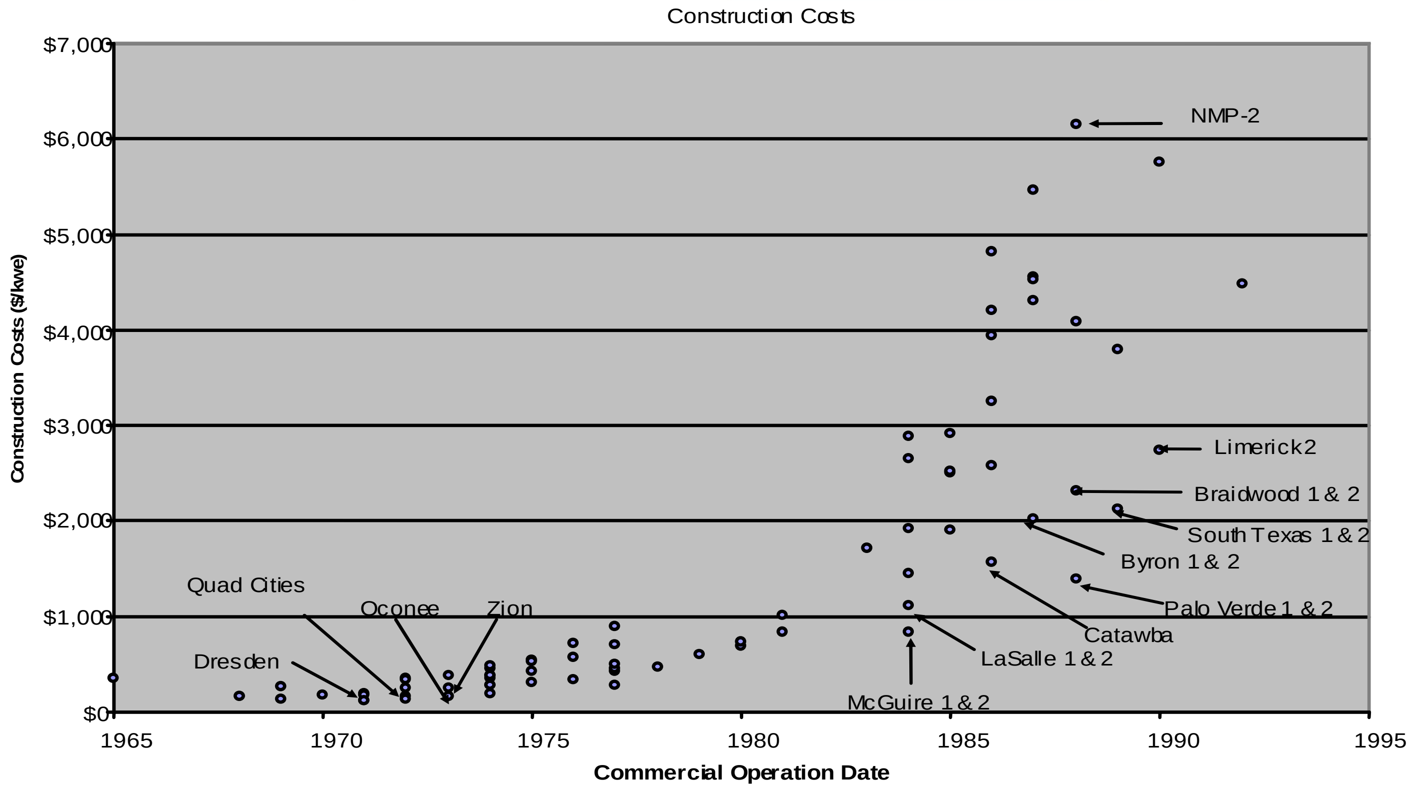
- Probable carbon controls or taxes
- Capacity factors
- Construction improvements
  - Batch concrete plants
  - Better unit rates
  - Large cranes and open containment
- Possibility of partial turnkey units
- Stabilization of O&M and capital additions

Without New Investments U.S. Nuclear Capacity Declines Quickly After 2030

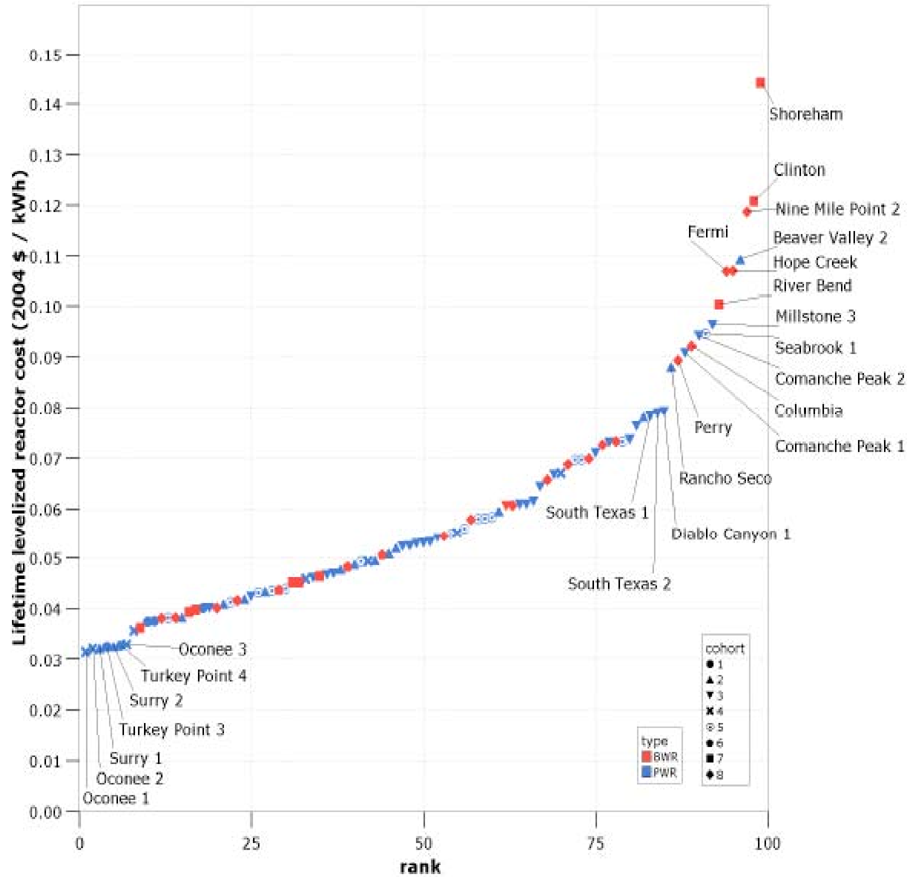


Source: Dominion Resources, 2005

Background – Industry Experience "Last Time"



Mike Wallace (President, Constellation Energy Group, "Managing the Risk of New Nuclear Plant Deployment," 2006. These numbers are all in mixed current dollars. Koomey and Hultman properly convert these into real dollars in an article submitted to Energy Policy.



Hultman, Nathan, Jonathan Koomey, and Dan Kammen, 2007. “What history can teach us about the future costs of nuclear power." *Environmental Science and Technology, in press.*

Historical US Construction Cost Experience
75 (pre-TMI-2 plants operating in 1986; $2002)

Construction start	Estimated Overnight	Actual Overnight	% Over
1966-1967	$560/kW	$1170/kW	209%
1968-1969	$679/kW	$2000/kW	294%
1970-1971	$760/kW	$2650/kW	348%
1972-1973	$1117/kW	$3555/kW	318%
1974-1975	$1156/kW	$4410/kW	381%
1976-1977	$1493/kW	$4008/kW	269%

Mark Gielecki and James Hewlett, Commercial Nuclear Power in the United States: Problems and Prospects, US Energy Information Administration, August 1994.

New Reactor Economics

- Some studies estimate very low costs for new plants (various year dollars)
  - GE/Westinghouse ($1000-1500/kW)
  - French Ministry of Economics, Finance, and Industry ($1664/kW)
  - University of Chicago ($1500/kW)
  - World Nuclear Association ($1000-1500/kW)
  - MIT Nuclear Study ($2000/kW)
  - US Energy Information Administration ($2083/kW)
  - UK Royal Academy of Engineering ($2241/kW)
  - Canadian Electricity Research Institute ($2347/kW)
  - Finland (Tarjanne and Luostarinen) ($2470/kW)

Good and Bad News?

- Clear evidence of construction improvements in Asia – e.g., 3x higher unit rates for structural concrete emplacement vs prior Asian experience or US experience
- More standardized design and faster licensing
- Most are based on **vendor projections**, reference each other, and are not products of neutral parties
- Generally omit owners costs and contingency (20%), and reduce follow-on unit costs by **both** subtracting "first of a kind" engineering costs and assuming learning curve
- 4-5 year construction time and easy financing
- **None considers recent increases in materials costs, or assumes real escalation during construction**

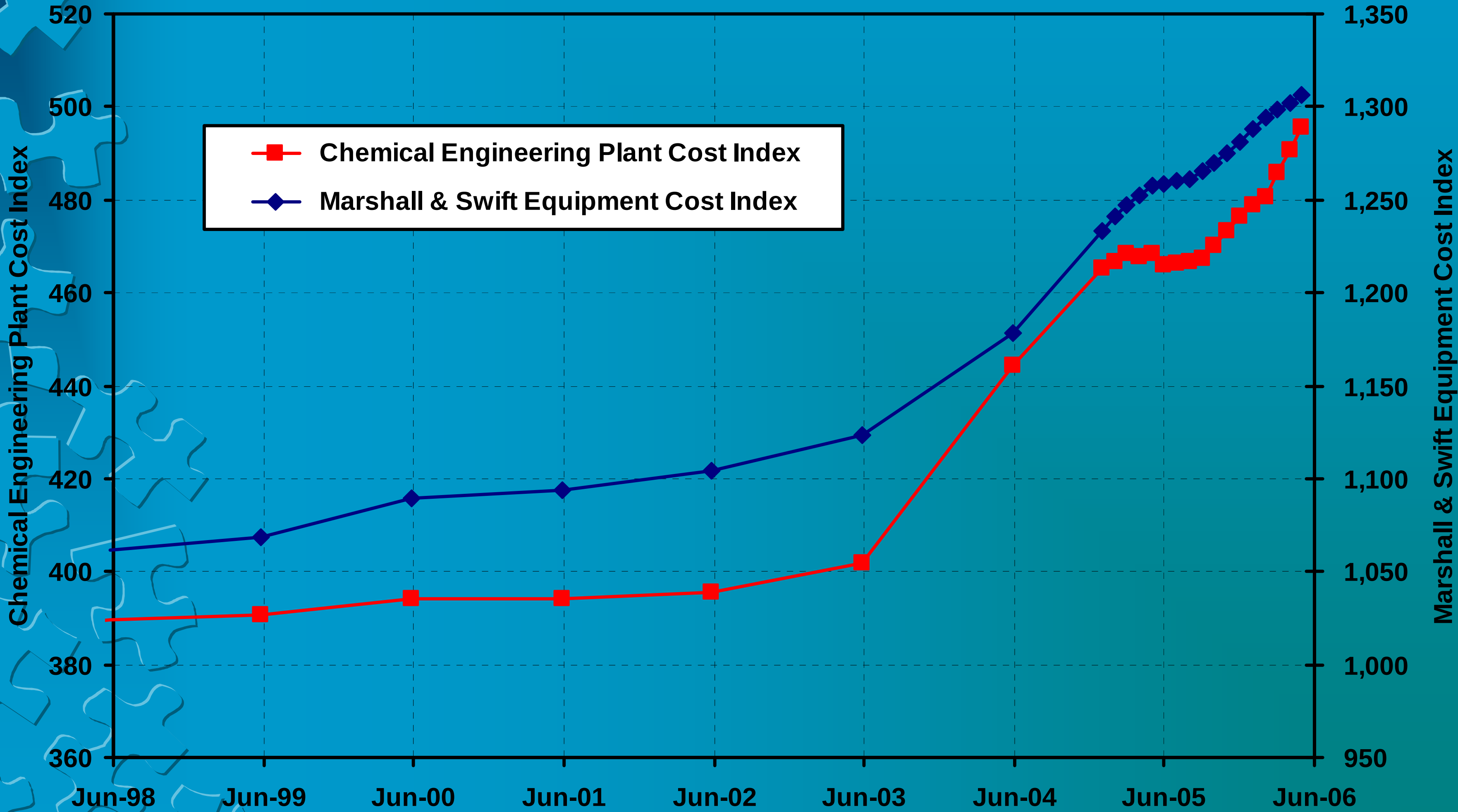
How About Actual Experience?

- No current US experience
- Some recent Asian experience is available (in overnight $2002)
  - Genkai 3 (Japan, COD 1994) $2818/kW
  - Genkai 4 (Japan, COD 1997) $2288/kW
  - Onagawa (Japan, COD, 2002) $2409/kW
  - KK6 (Japan, COD, 1996) $2020/kW
  - KK7 (Japan, COD, 1997) $1790/kW
  - Yonggwang 5 and 6 (S Korea, 2004/5) $1800/kW
  - Olkiluoto 3 (Finland 2010-2011) $2500-3000/kW

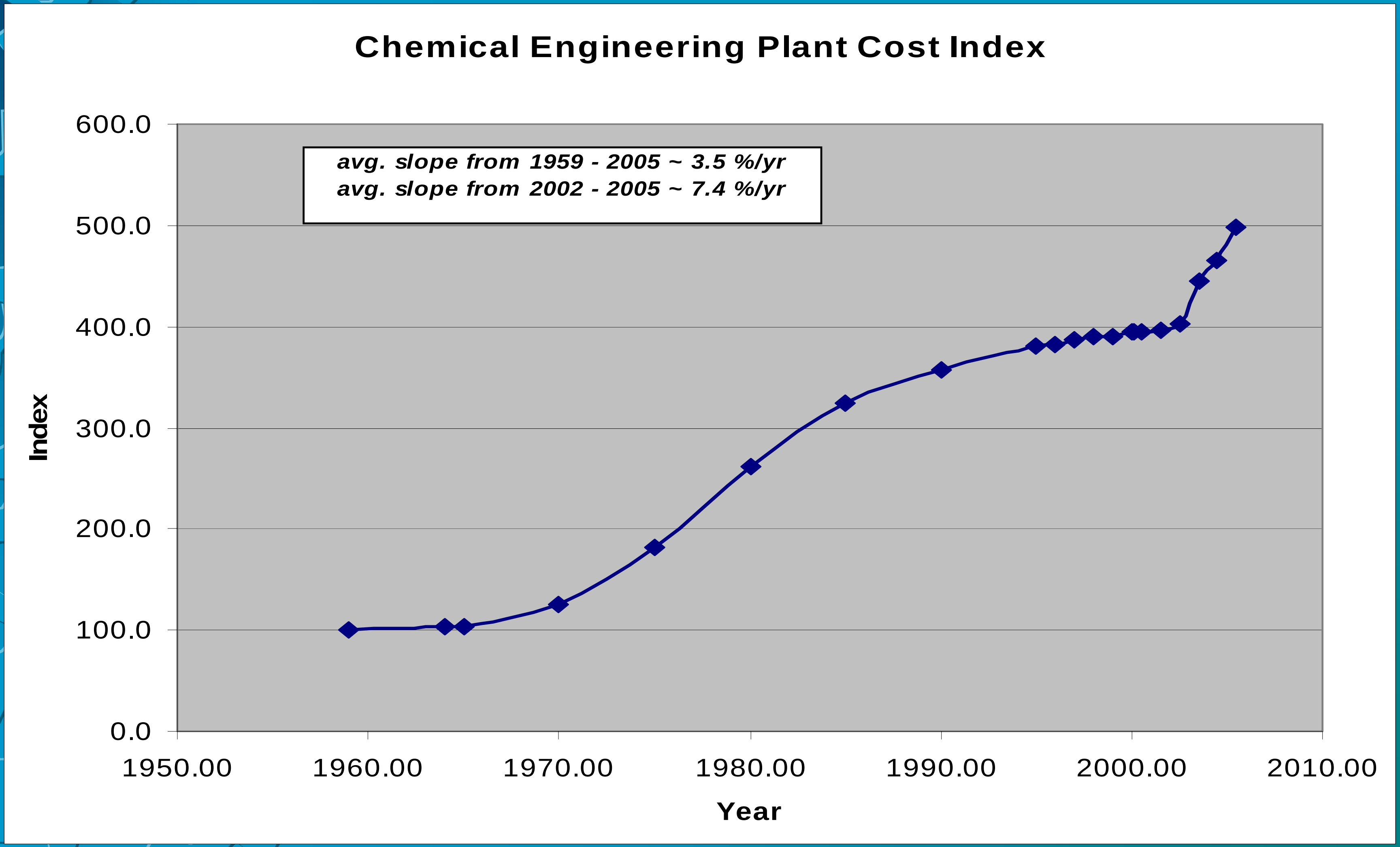
Where To From There?

- Average cost of $2130/kW in 2002 dollars for seven recent units
- **Escalate to 2007 dollars**
  - Assume range of real escalation from 2002-2007 and beyond
  - 4 percent real from 2002, and 0-4 percent real thereafter
- **Assume potentially longer development period**
  - 2 years pre-construction
  - 5-6 years construction
- **Assume current fleet average for capacity factor and O&M**
  - 75-90 percent
  - $80-$100/kW-yr fixed O&M, not including A&G (admin overheads)
  - $20-30/kW-yr capital additions
- **Evaluate impact of nuclear fuel cost increases**
  - 7x increase in natural uranium price (2002-2007)
  - Probable 2-3x increase in enrichment services (2007-2012)
- **Vastly different regulatory/financing environment**
  - Probable equity risk premium for nuclear investments
  - Potential construction cost caps as condition of moving forward

Construction Cost Indices
Source: Chemical Engineering Magazine, August 2006

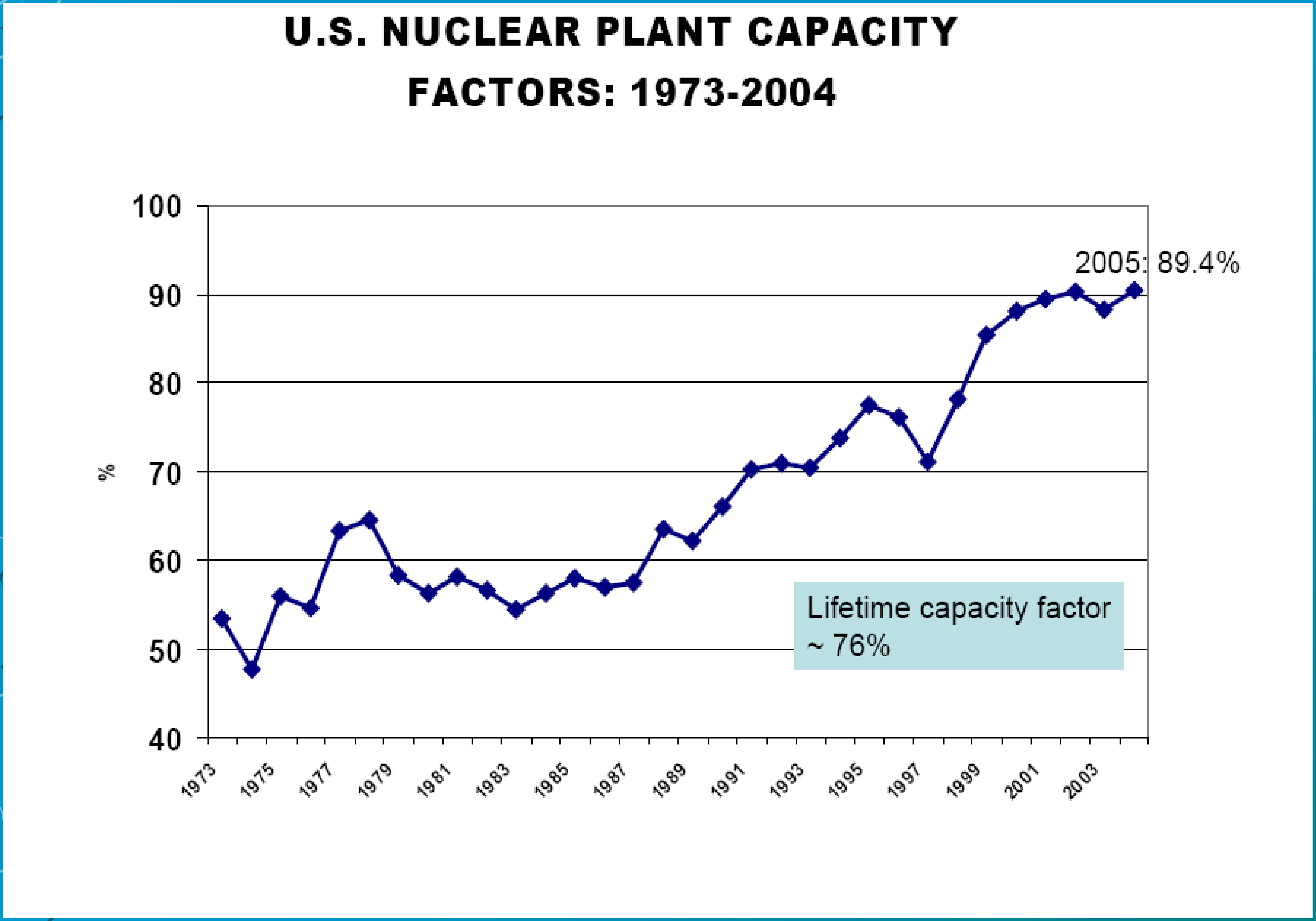


Chemical Engineering Plant Cost Index (1956-2006)

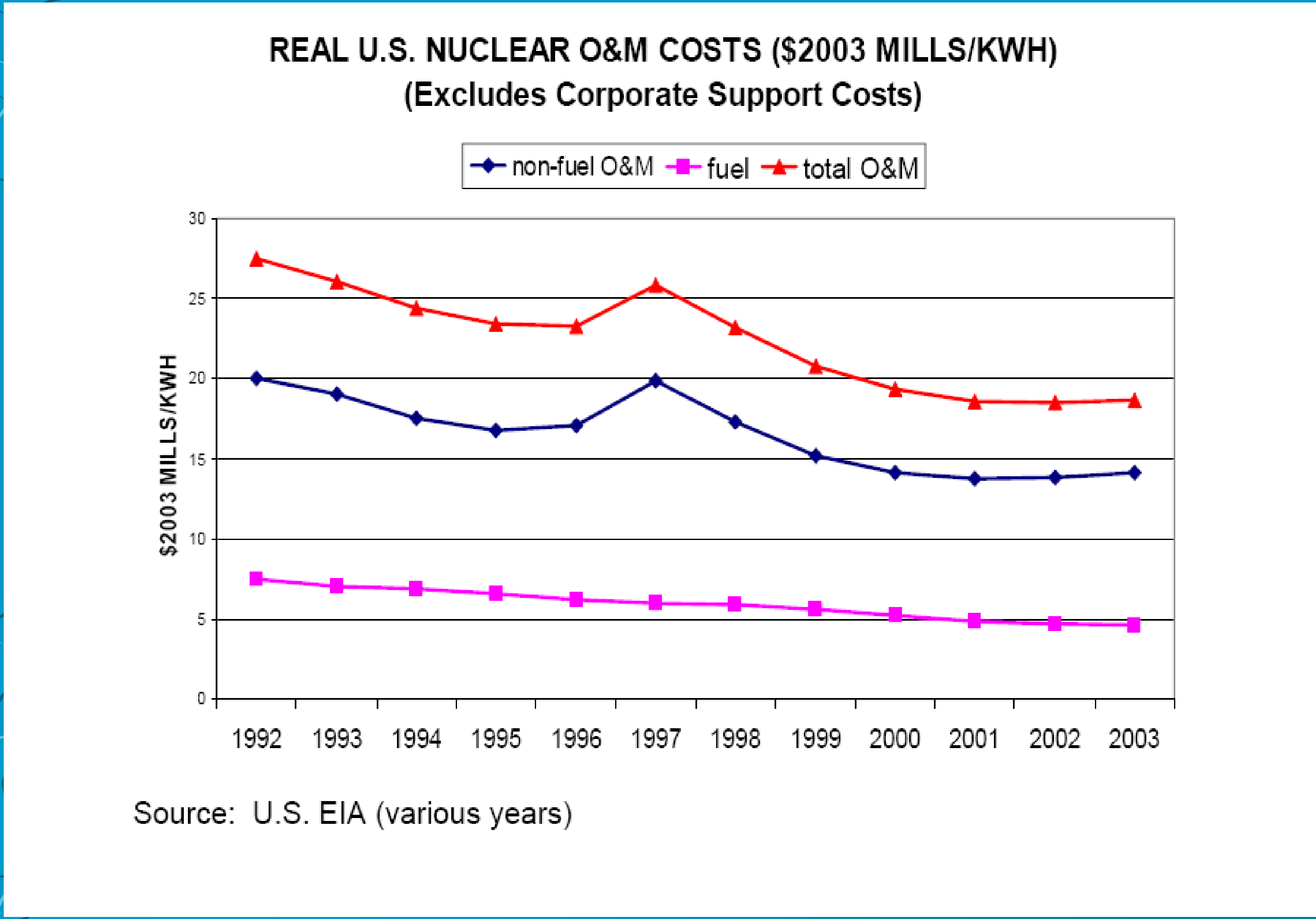


Learning Curves and Growth Pains

- There are good arguments for assuming a learning curve
  - More standardized design
  - More experienced contractors and construction crews
  - More choice and competition among suppliers and sub-suppliers
- But, "learning curves" can go in reverse, driven by:
  - Skilled labor and materials shortages
    - GE/Toshiba study for TVA Bellefonte rejected 4x10 work week because of insufficient skilled labor within 400 mile radius
    - Only one steel mill – in Japan – currently available for pressure vessel forgings
    - Other pinch points throughout the supply chain, with potential for monopoly pricing
  - Fragmented market structure – different utilities; different contractors
  - Questionable public acceptance of a second repository
  - Growing concern and opposition, regulatory delays, and possible loss of investor and utility confidence



Paul Joskow, Prospects for Nuclear Power – A US Perspective, presentation at the University of Paris, May 2006. ***This graph does not include premature shutdowns, which would reduce annual averages by 5-10 percentage points.***

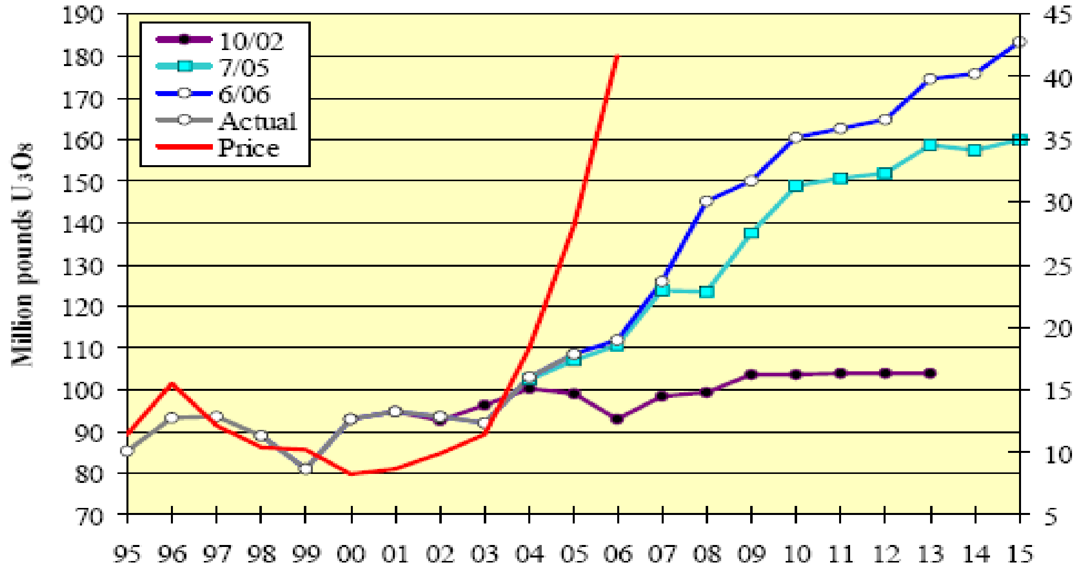


Also taken from Joskow, 2006. **O&M costs only include those reported in FERC accounts 501-555, not overheads reported in 920-932, e.g., $25 million/year or about 4 mills/kWh for Energy Northwest's Columbia Generating Station**.

Fuel Supply Issues

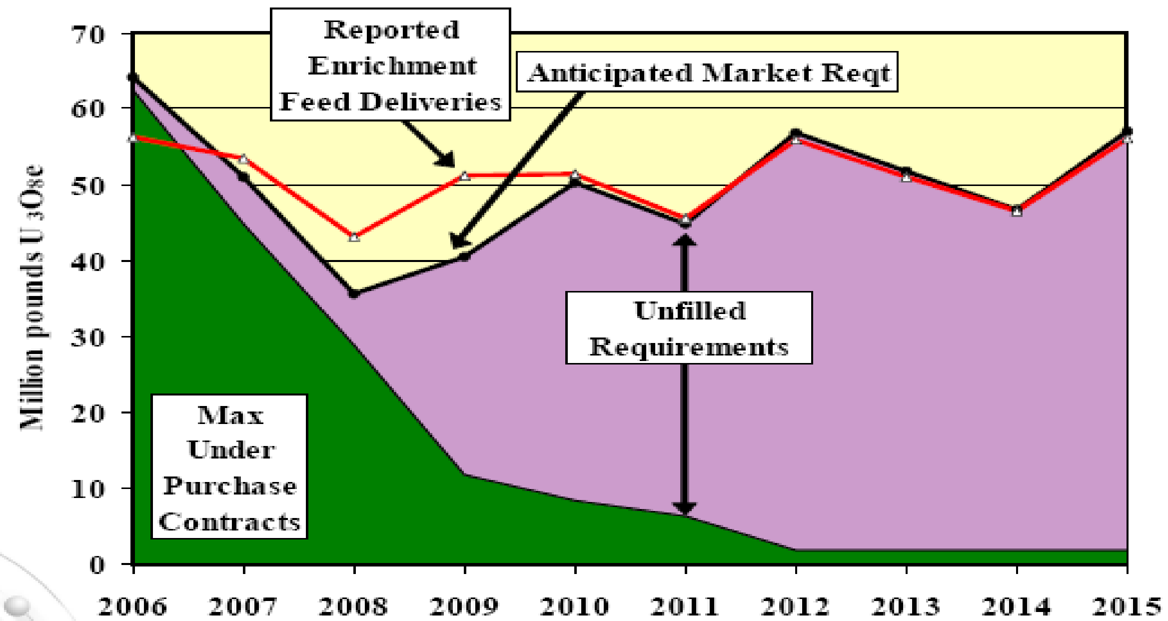
- Western uranium production (37 kTU) is about half current consumption (62 kTU)! So where does the rest come from?
  - Excess utility inventories from cancelled and shutdown plants (1980-1990s)
  - Russian imports (1990s)
  - US government inventories when enrichment privatized (1998-2006)
  - Surplus Russian weapons uranium (1999-2013)
  - So – prices well below cost, short term contracts with price ceilings, no new development
- Enrichment capacity is also priced below marginal cost
  - New plants would lose money at current price
  - Low uranium prices led to 25% higher output with more uranium wasted
  - Higher prices cut output by the same fraction – probably not possible
- This one is worse than California’s failed electricity market experiment

Changes in U Production Plans



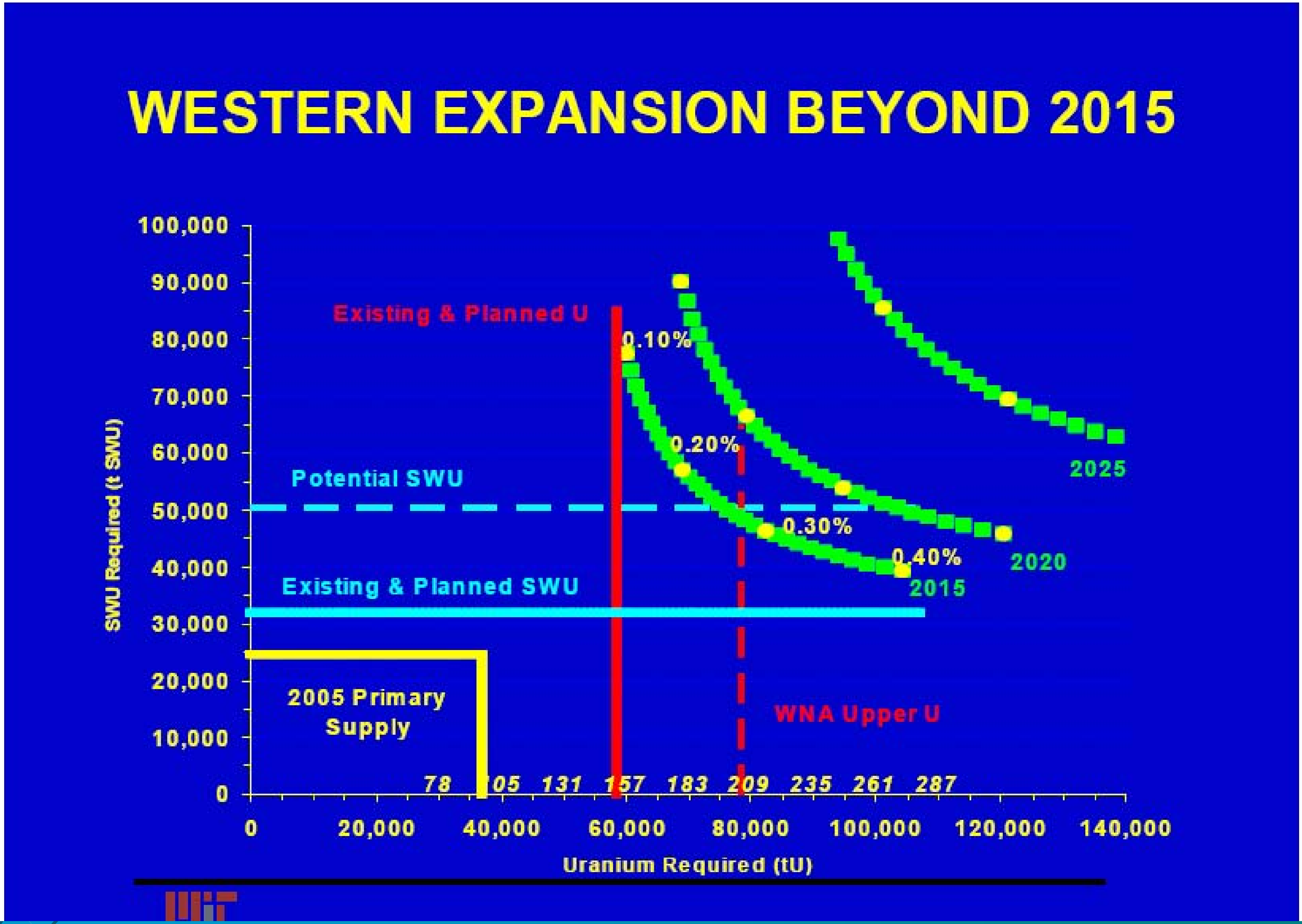
Jeff Combs, President, Ux Consulting Company, Price Expectations and Price Formation, presentation to Nuclear Energy Institute International Uranium Fuel Seminar, October 2006. Prices today are $72/lb.

EIA Anticipated U.S. Uranium Market Requirements



Source: EIA *Uranium Marketing Annual Report*, May 2006

Combs, 2006



Tom Neff (MIT), Uranium and Enrichment: Enough Fuel for the Nuclear Renaissance?, December 2006.

FUELING THE NUCLEAR RENAISSANCE

- Substantial new orders for reactors will require heroic efforts to expand primary uranium & enrichment supply
- Secondary supply is highly problematic (MOX, Russian exports, HEU, government sales)
- Utilities will start seeking fuel when they order reactors, likely before new supply is available—problems arise sooner than charts show
- Prices will rise for U and SWU, perhaps above historical levels ($120/lb U_3O_8 ($315/kgU), $250/SWU in 2006 USD)

Tom Neff, MIT

Does Reprocessing Help?

Fuel cycle steps	MIT	This analysis
Uranium	$30/kg	$150-300/kg
Enrichment	$100/SWU	$130-300/SWU
Fabrication	$275/kg	$275/kg
Disposal	$400/kg	$400/kg
Reprocessing	$1000/kg	$1250-2000/kg
Fuel cycle cost		
Open	5 mills/kWh	12-16 mills/kWh
Closed	20 mills/kWh	21-35 mills/kWh
Differential	4x	1.3-3x

But….

- Reprocessing is very capital intensive
  - Rokkasho (Japan) - $18 billion/800 MTHM/yr
  - More than $2200/kg just for capital return
- Large profit margins – and much better investment potential - in both uranium and enrichment
- The bubbles will burst some time, creating risks only governments can absorb

Possible Assumptions and Results

- High Case
  - 4% real escalation from 2002-2007 and through 6-yr completion
  - 50/50 debt equity, with 3% equity premium
  - 75 percent lifetime capacity factor
  - Higher fuel cycle costs (2-4x current levels)
  - Capital cost - $4540/kW ($4000/kW in 2007 dollars)
  - Levelized costs including interconnection – 10.7 cents/kWh
- Lower Case
  - 4% real escalation from 2002-2007, none thereafter, 5 year
  - 90 percent lifetime capacity factor
  - Higher fuel costs
  - Capital cost - $3600/kW ($3200/kW in 2007 dollars)
  - Levelized costs including interconnection – 8.1 cents/kWh

Major Uncertainties

- Learning Curve or "Reverse Learning Curve"
- Public acceptability and long view viability of streamlined NRC licensing
- Persistence of subsidies
- Availability of skilled craft, materials, and experienced contractors
- Willingness of vendors to take/share development risks
- Yucca Mountain suitability
- Regulatory and financing environment
- Value of carbon offsets
- Competition from other existing and emerging alternatives