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The Economics of Direct Disposal v. Reprocessing and Recycle

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Direct-disposal v. Reprocessing-Recycle

- Is it better to dispose of spent fuel directly in geologic repositories, or reprocess it to recover and recycle the plutonium and uranium?
- This question is receiving renewed attention, because of concerns about:
  - accumulations of spent fuel and separated plutonium
  - the capacity of geologic repositories
  - the long-term future of nuclear power
  - links between the civilian nuclear fuel cycle and the proliferation of nuclear weapons

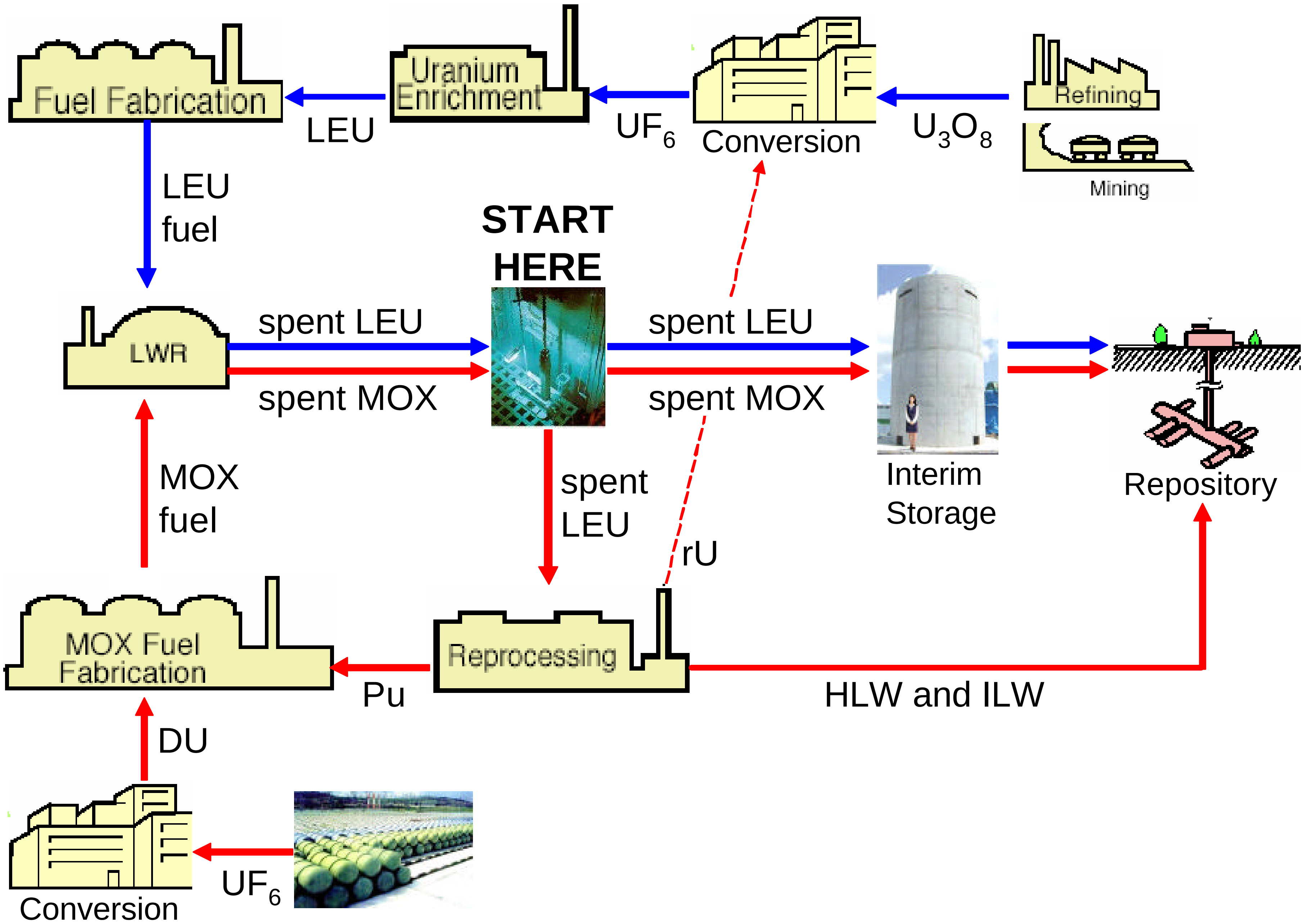
Our Study Focused on Costs

- Cost is an important element in this debate
  - not the only (or most important) factor; environmental, security, and waste-management concerns also important
- General agreement that reprocessing-recycle is more expensive than direct-disposal today
- Advocates argue that difference is small, will disappear soon if nuclear power grows
- We conclude that cost difference is significant and is likely to persist for 75-100 years

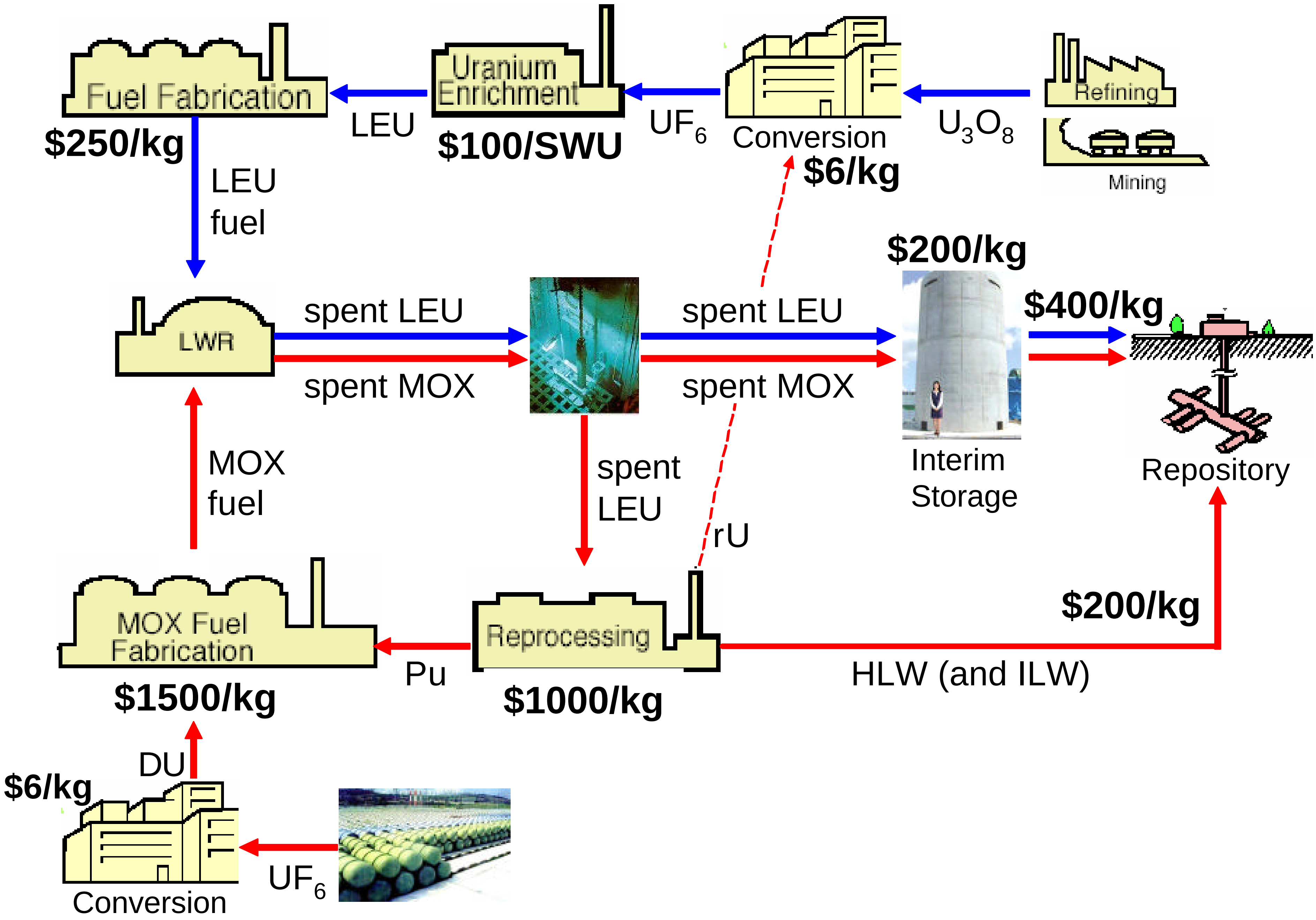
Outline

1. Direct-disposal v. reprocessing-recycle in LWRs
    - breakeven uranium price
    - difference in cost of electricity
    - sensitivity analysis
2. Direct disposal in LWRs v. recycle in FBRs
3. Uranium resources and prices
    - when will uranium price reach the breakeven price for reprocessing-recycle?
4. Impact of reprocessing-recycle on repository requirements

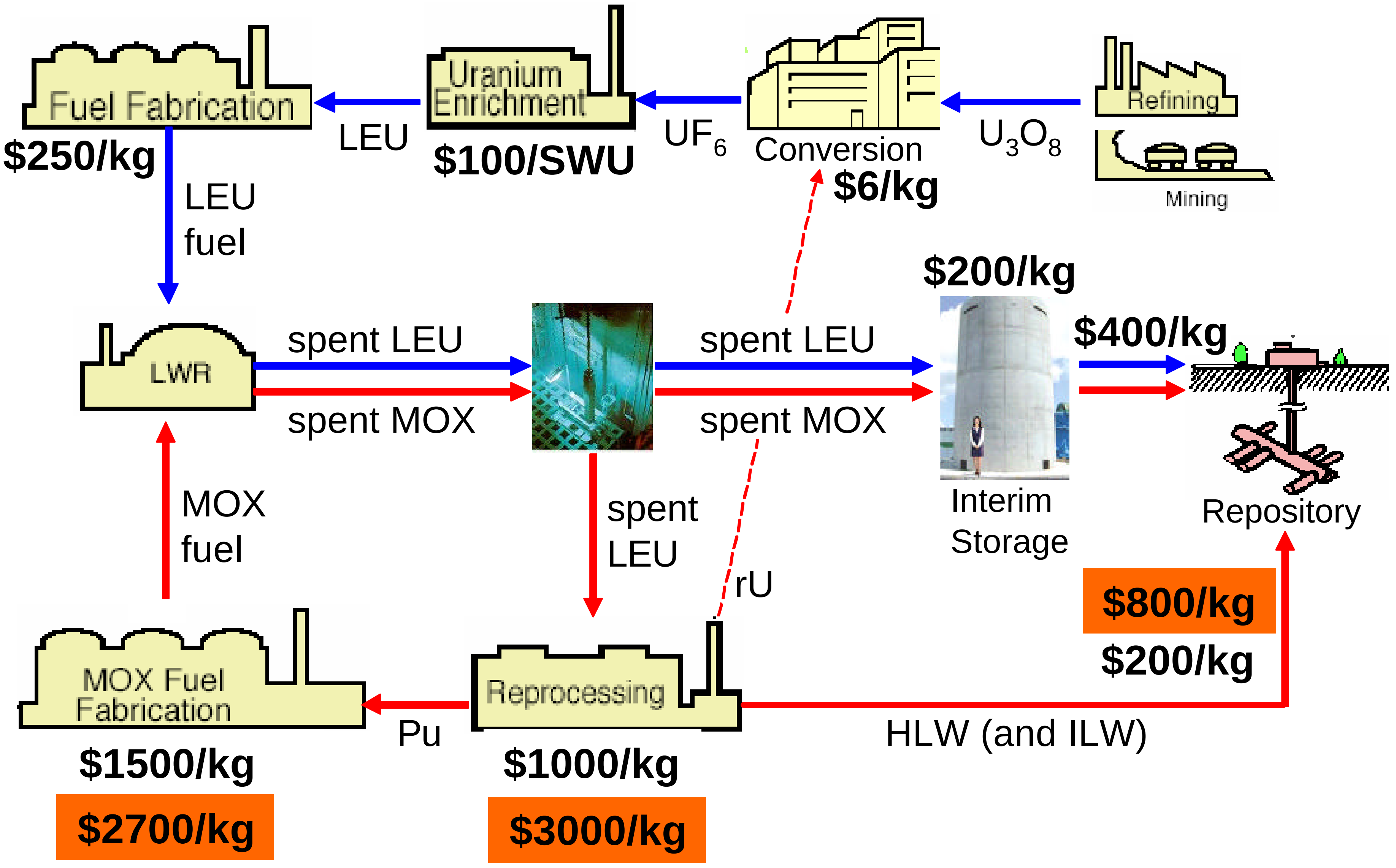
Direct Disposal v. Reprocessing in LWRs



Direct Disposal v. Reprocessing in LWRs



Direct Disposal v. Reprocessing in LWRs



For central values of the price of fuel-cycle services and other parameters, we calculate

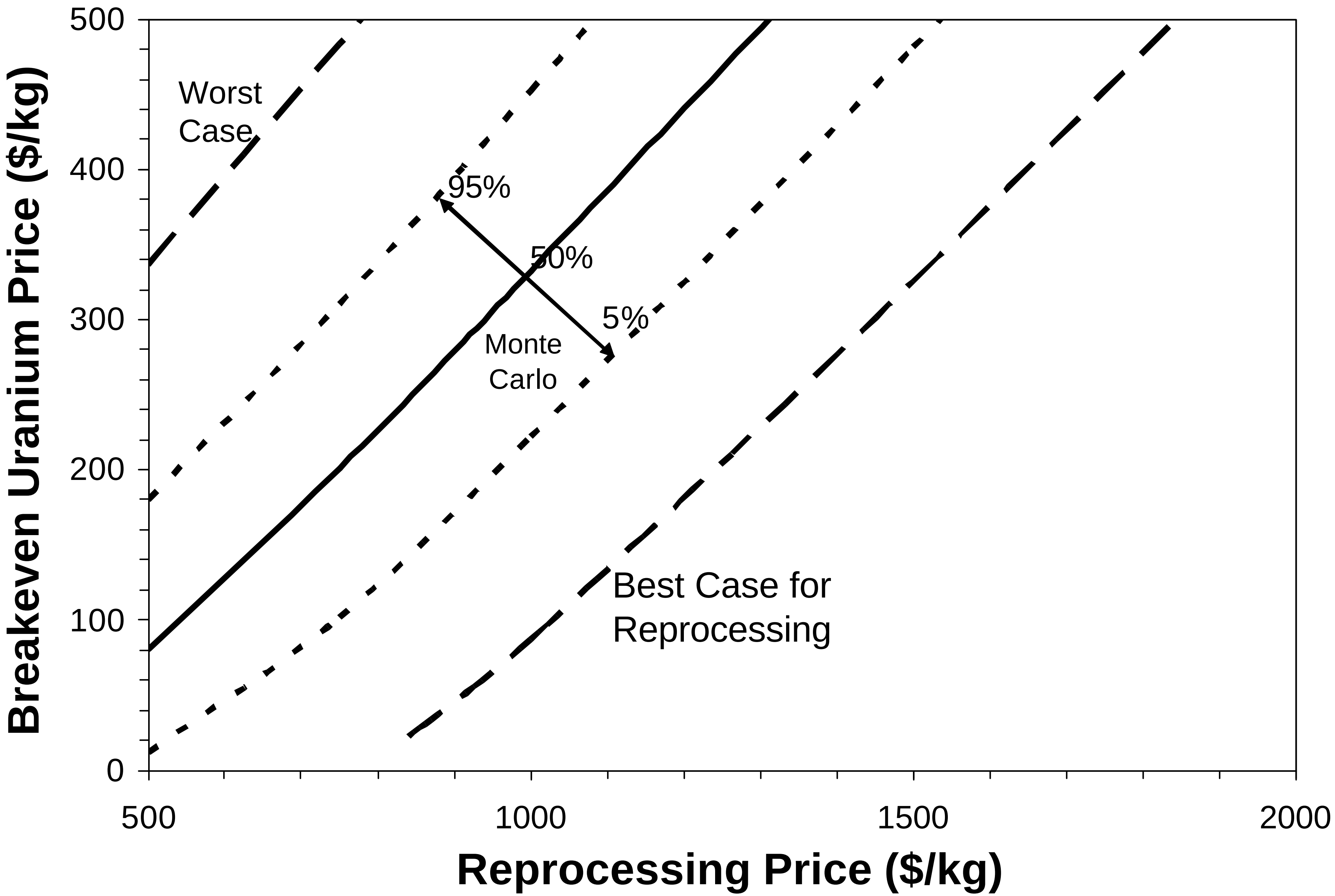
- the uranium price for which the cost of electricity would be the same for both options (the “breakeven price”)
- breakeven prices for other fuel-cycle services (e.g., reprocessing)
- the difference in the cost of electricity (COE), for a given uranium price

Breakeven Prices

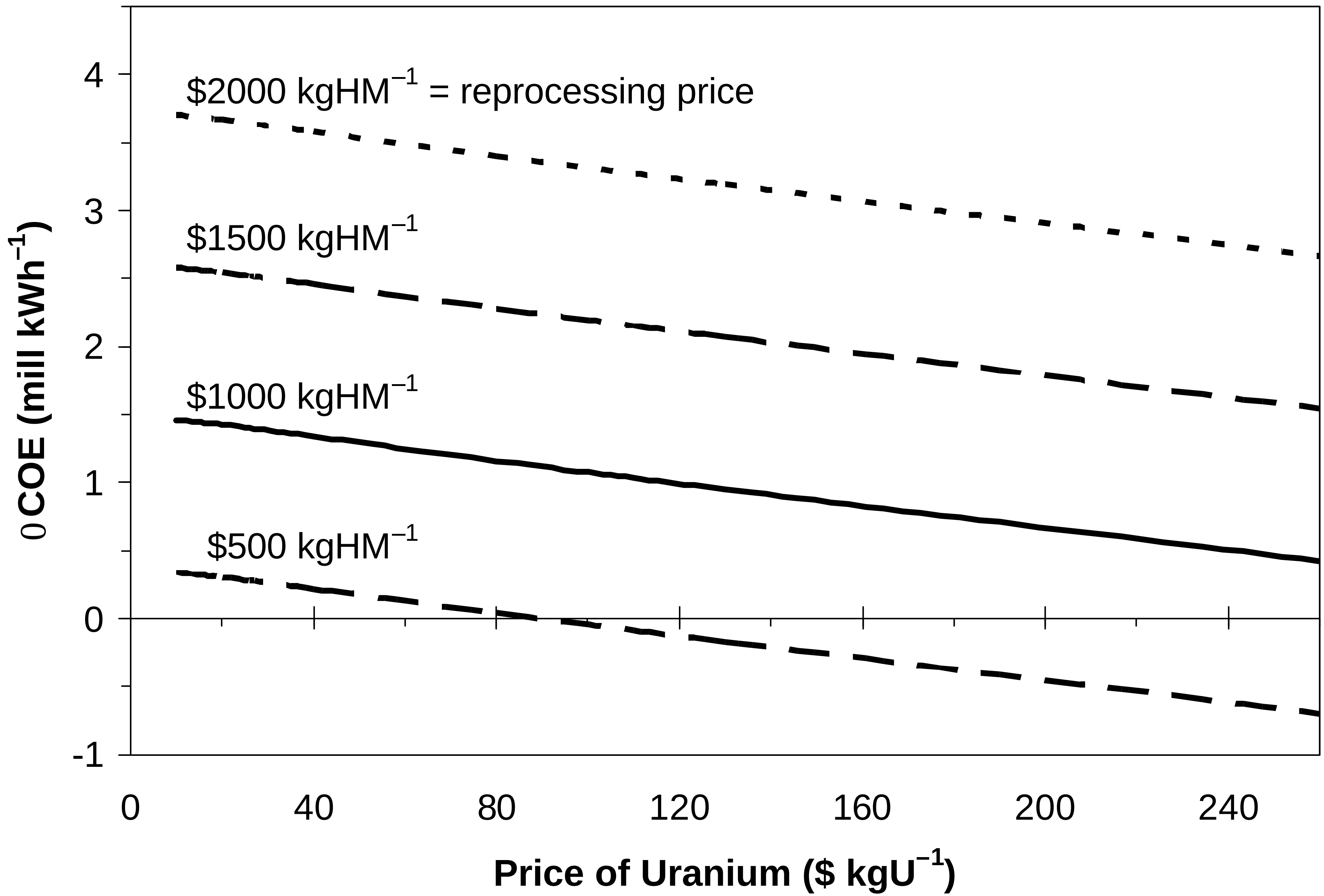
assuming central values of other parameters

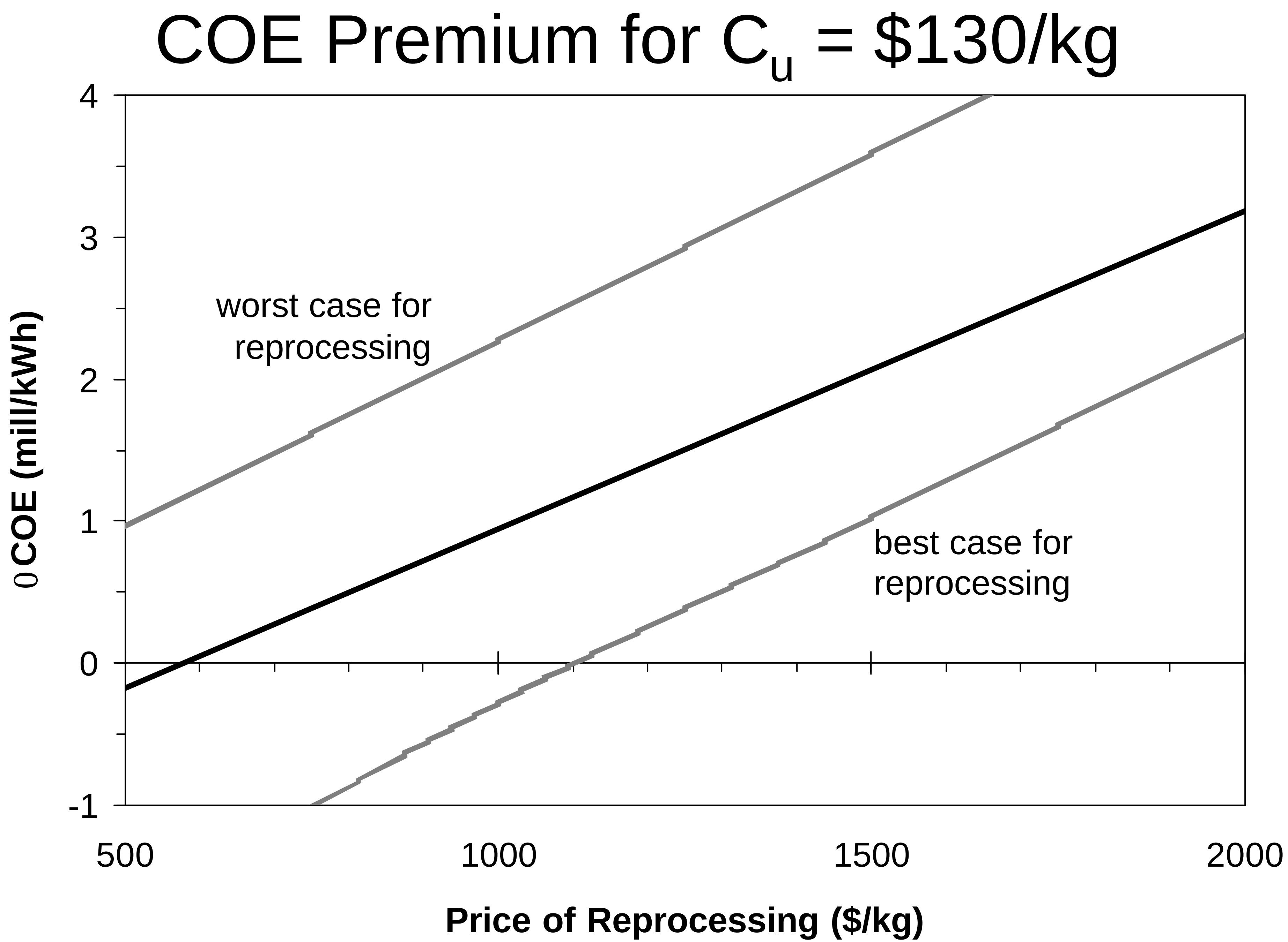
Parameter	**Break-even**	**best**	**central**	**worst**
Uranium ($/kg)	**370**		50	
Reprocessing ($/kg)	**420**	500	1000	2000
MOX fabrication ($/kg)	**<0**	700	1500	2300
Interim fuel storage	**780**	300	200	100
Disposal cost difference	**630**	300	200	100
Enrichment ($/SWU)	**1200**	150	100	50

Breakeven U Price v. Reprocessing Price



COE Premium for Reprocessing-Recycle

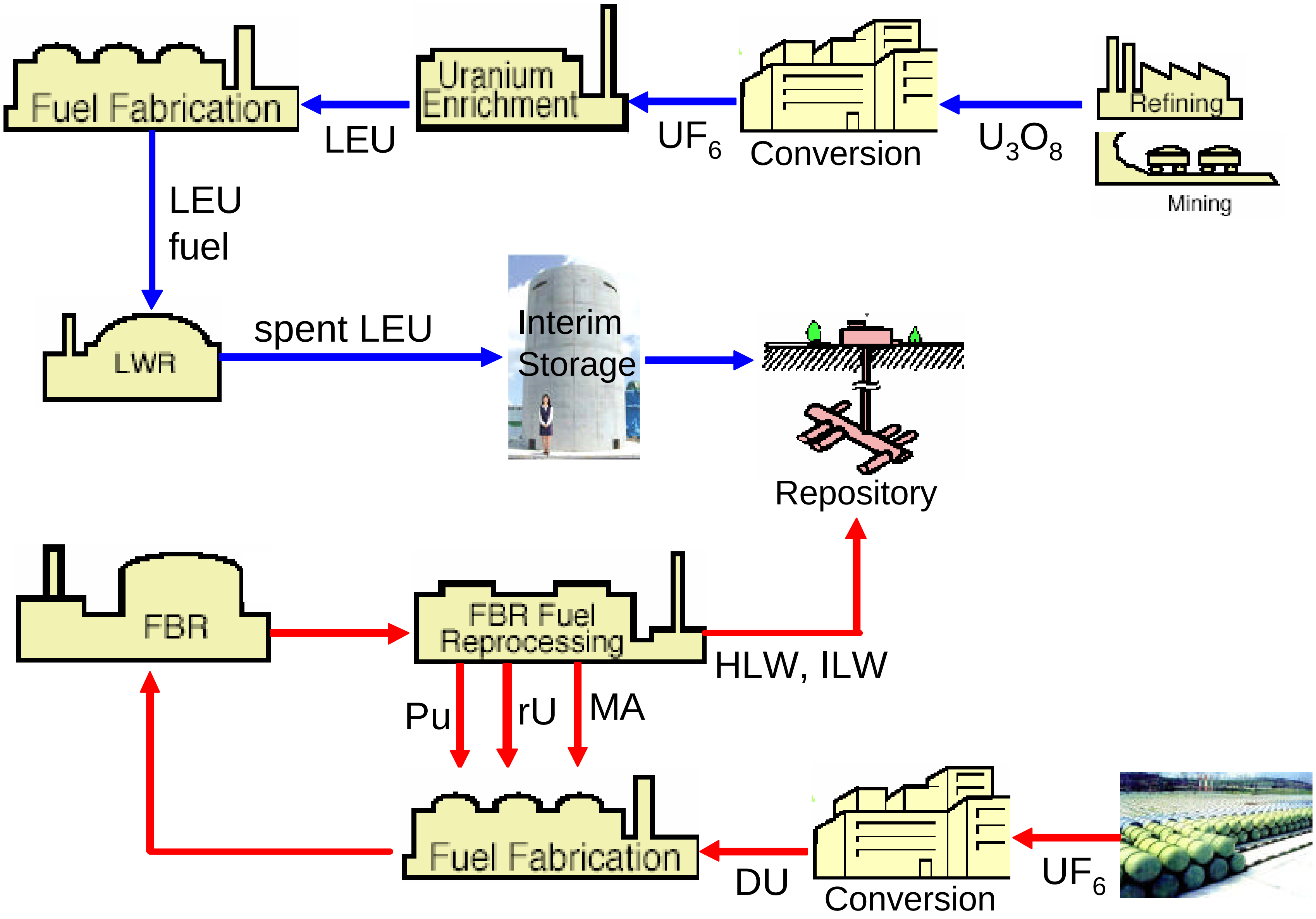



COE Premium for C_u = $130/kg
0COE (mill/kWh)
4
3
2
1
0
-1
worst case for reprocessing
best case for reprocessing
500
1000
1500
2000
Price of Reprocessing ($/kg)

These estimates are favorable to reprocessing

- Central values of reprocessing and MOX fuel fabrication are well below recent prices
- No charge included for Pu storage, Am removal, licensing or security for MOX use
- Expensive interim storage included for direct-disposal
- Disposal cost savings for HLW higher than other estimates
- Equal disposal costs for spent MOX and LEU

LWR (direct disposal) v. FBR

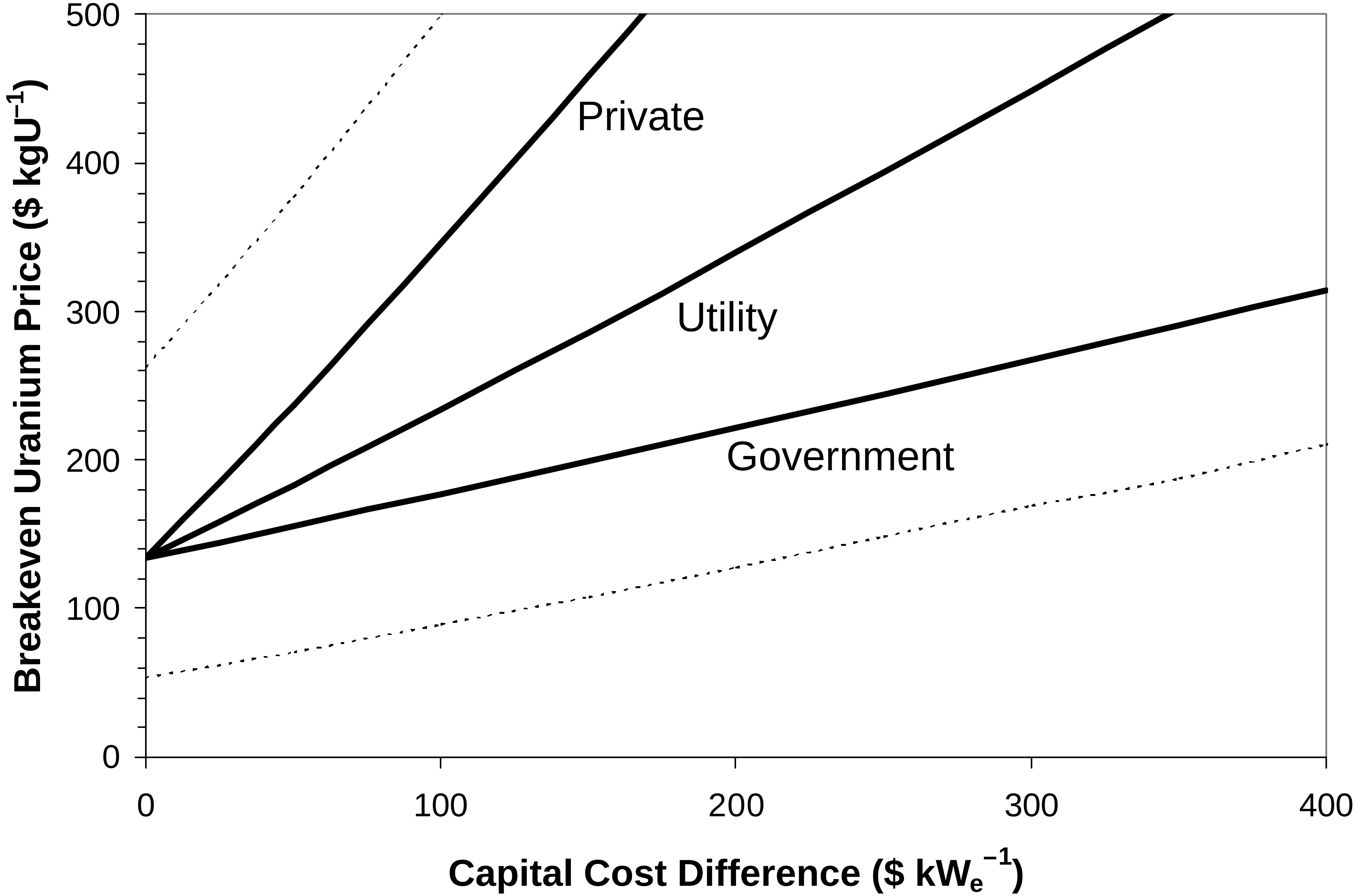


Breakeven Prices

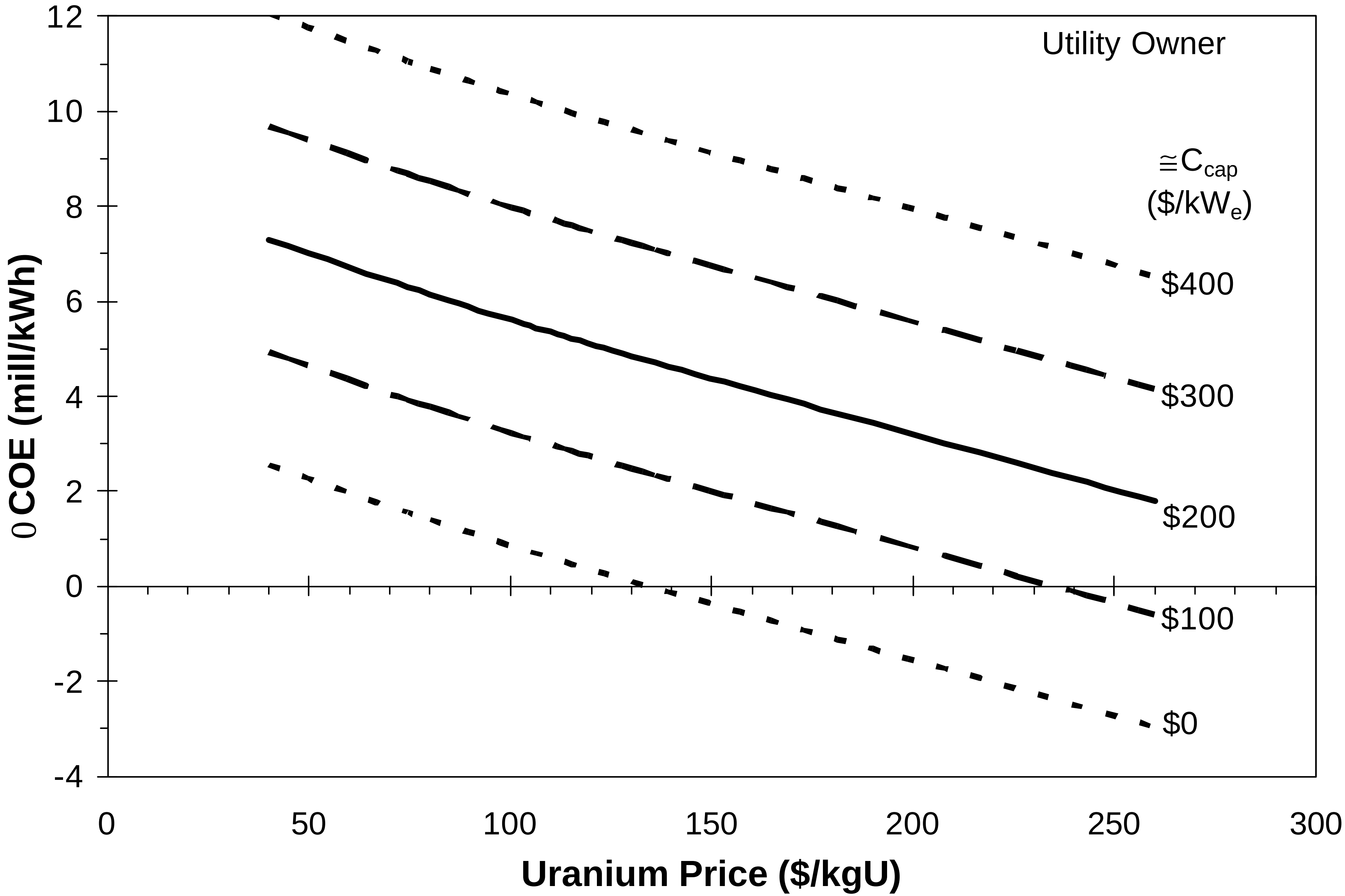
assuming regulated utility ownership

Parameter	**Break-even**	**best**	**central**	**worst**
Uranium ($/kg)	**340**		50	
Capital Cost Difference	**–95**	0	200	400
Reprocessing ($/kg)	**<0**	500	1000	2000
Interim fuel storage	**4100**	300	200	100
Disposal cost difference	**3400**	300	200	100
Enrichment ($/SWU)	**570**	150	100	50

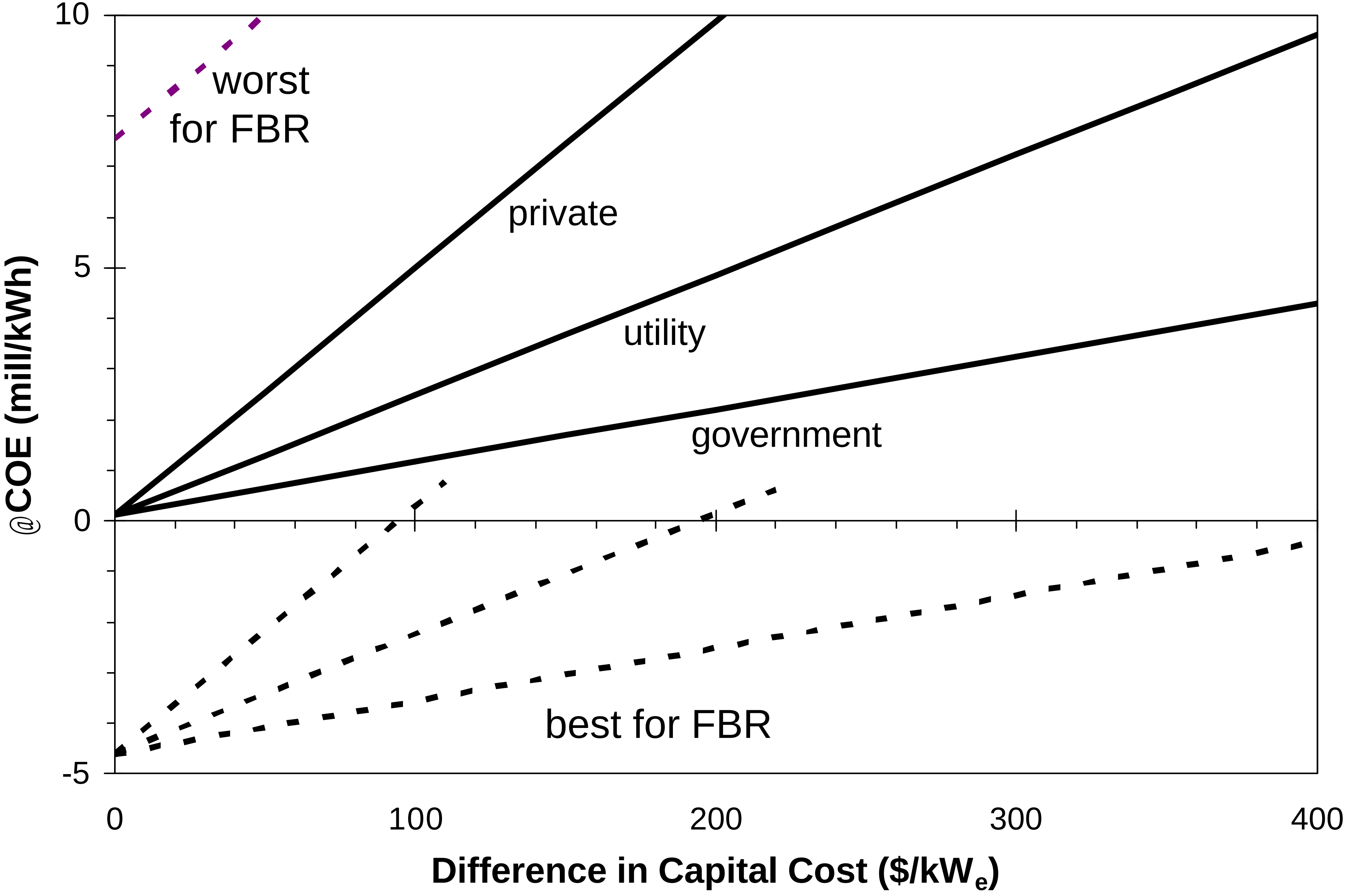
Breakeven U Price v. Capital Cost Difference



COE Premium for FBR



COE Premium for C_u = $130/kg



Uranium Resources

- Breakeven U prices using central values:

  $340/kg (FBR) $370/kg (LWR)

- Breakeven U price > $130/kg even in best case
- How much is available? Red Book gives 16 Mt available at $130/kg or less, but…
  - high-cost resources in many countries (e.g., Australia) not estimated;
  - unconventional resources (e.g., phosphates) not included;
  - little investment in exploration

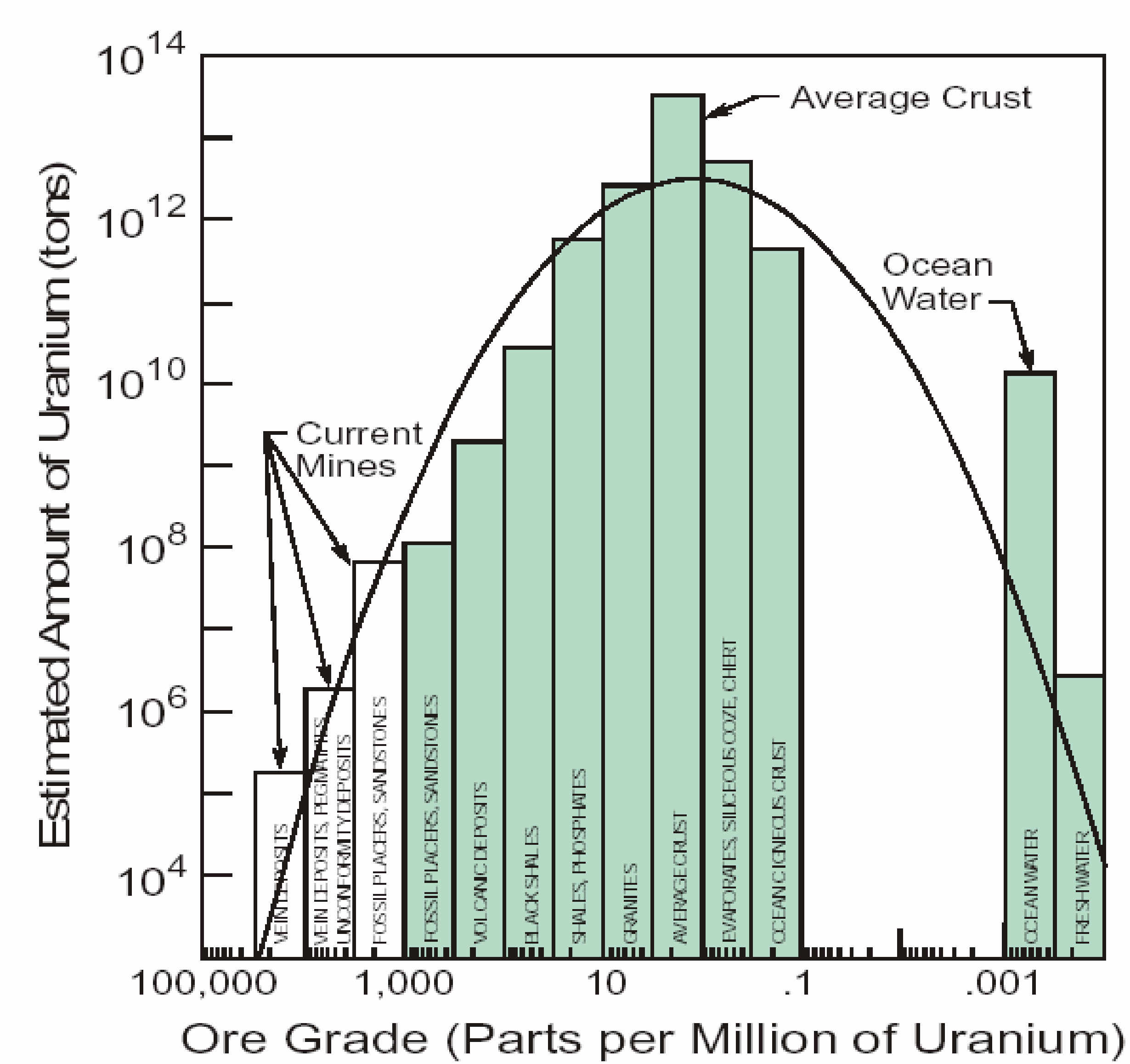
A Very Rough Estimate of Ultimately Recoverable Uranium Resources

- Red Book give 2.1 Mt at $40/kg (~current price)
- Hore-Lacy: “a doubling of price from present levels could be expected to create a tenfold increase in measured resources.”
- So there should be 21 Mt available at $80/kg and 210 Mt at $160/kg

$$R = 2.1\left(\frac{p}{40}\right)^{\varepsilon}$$

ε = long-term price elasticity of supply

Deffeyes and MacGregor (1980)

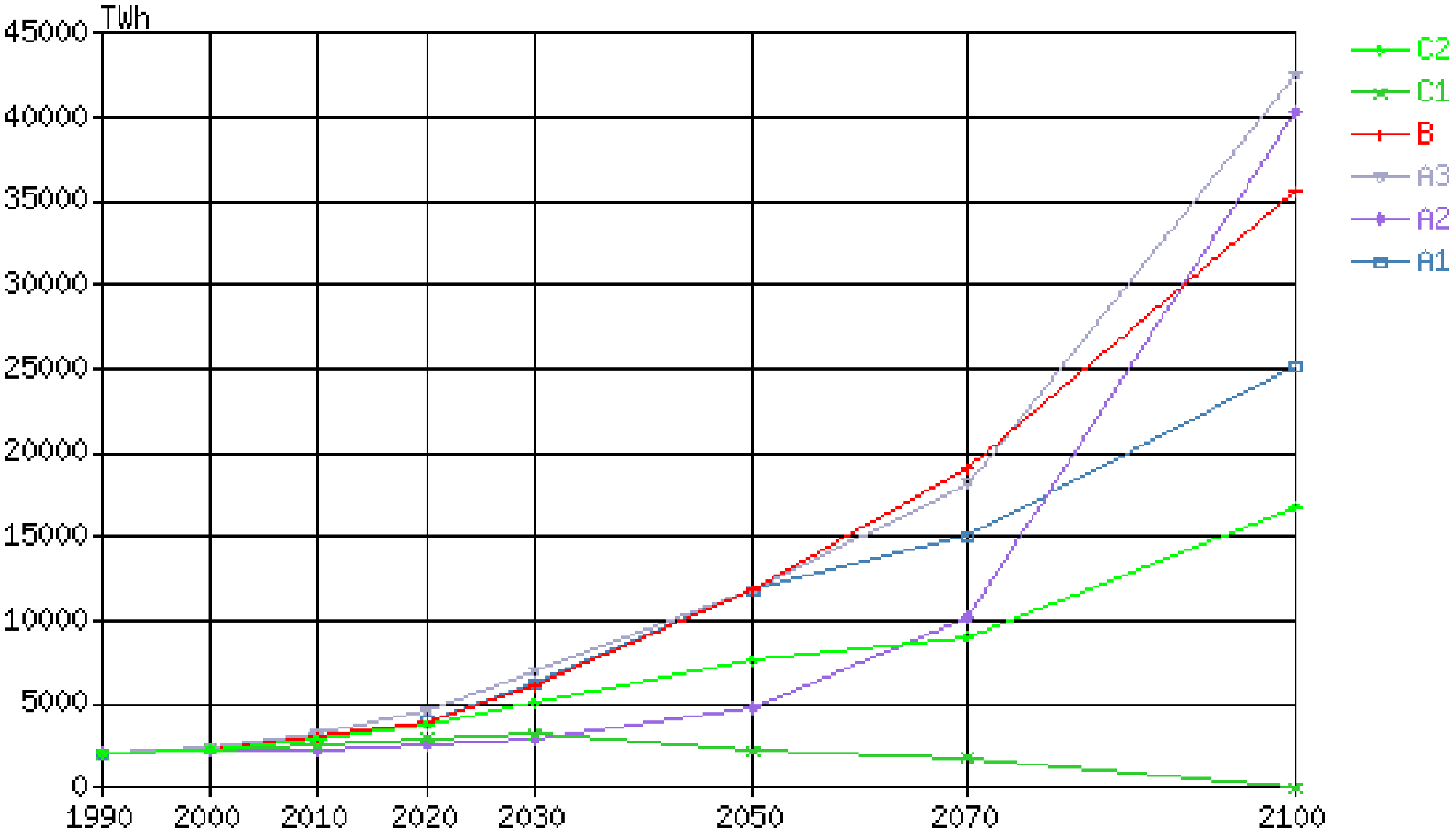


On average, a 10-fold decrease in ore grade is associated with a 300-fold increase in available resource

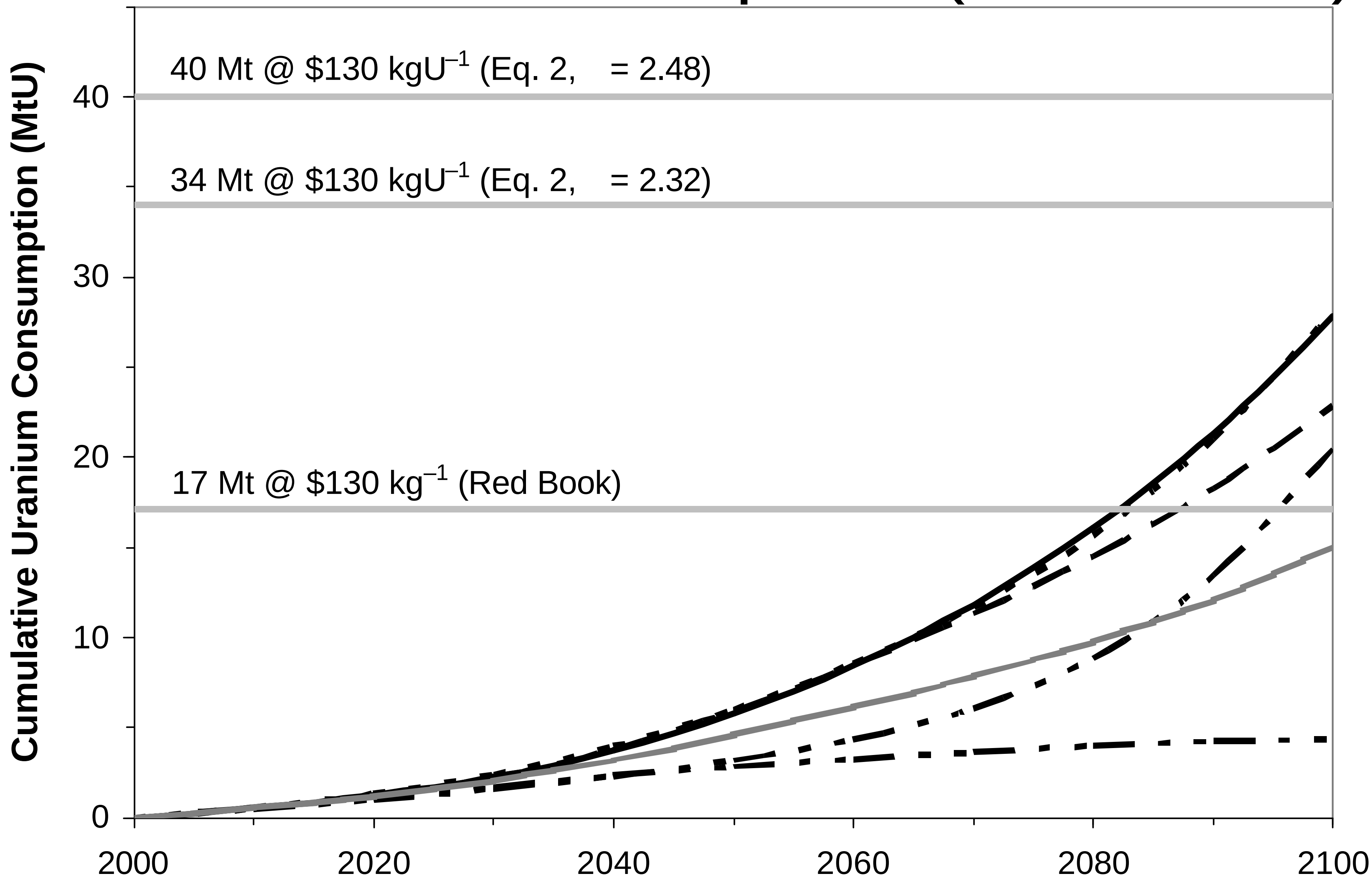
Recoverable Resources

Source	Long-term elasticity of supply ε	MtU recoverable at price less than		
		$40	$80	$130
UIC (doubling price creates ten-fold increase in measured resources)	3.32	2.1	21	105
Deffeyes and MacGregor (ten-fold decrease in concentration = 300-fold increase in resource, p ~ c)	2.48	2.1	12	39
Gen-IV (based on U.S. reserves for various mining methods)	2.35	2.1	11	34
Red Book		2.1	11	16

IIASA/WEC Global Energy Perspectives Nuclear Electricity Production Scenarios



Cumulative Uranium Consumption LWRs with Direct Disposal (19 tU/TWh)



Other Considerations

- Repository space
- Energy security
- Nonproliferation
- Public and environmental health

Repository Space

- Can reprocessing substantially reduce need for new repositories?
- Recycle in LWRs: no
  - buildup of minor actinides increases decay heat per kWh
- Recycle in FRs with minor actinides : yes, but…
  - reprocessing, fabrication more expensive
    - Gen-IV: \$2000/kg reprocessing, \$2600/kg core fuel
    - if C_U = \$130/kg:

      ΔCOE = 6 mill/kWh if ΔC_{cap} = \$0

      16 mill/kWh if ΔC_{cap} = \$200/kW_e

Repository Space

- Repository space is scarce because of political barriers to new repositories, but
  - most countries can greatly expand repository capacity without new site (but not US)
  - some countries may accept foreign waste, given very high willingness to pay for service
  - political barriers to separation and transmutation are unlikely to be smaller than barriers to new repositories, especially given much greater near-term risks

Energy Security

- Large number of uranium suppliers ensures an open and competitive world market
  - Canada, US, Australia, Russia, Kazakhstan, Uzbekistan, South Africa…
- Establishing a “strategic uranium reserve” would cost less than reprocessing
  - 1 mill/kWh sufficient to fund a 20-year supply of uranium

Nonproliferation

- Once-through fuel cycle is generally regarded as being the most proliferation-resistant
  - Pu in spent fuel can be recovered only by reprocessing; radiation provides self-protection for hundreds of years
  - Enrichment plants relatively easy to safeguard
- Recycle fuel cycles pose larger risks:
  - Theft of separated Pu in storage, fresh MOX
  - Reprocessing plants difficult to safeguard
  - Risks associated with enrichment, spent fuel avoided only with FBRs and full MA recycle

Public and Environmental Health

- Except for accidents, radiation doses to public are very low for both fuel cycles
- Reprocessing and recycling does not significantly reduce the risks from waste disposal
  - risks usually dominated by long-lived, water-soluble fission products (Tc-99, I-129)
- Reprocessing and recycling reduces risks from uranium mining, but increases risks from accidents (at reactors and reprocessing plants)