Perspectives on the Economics of Nuclear Power from the MIT Study

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What the Study did

Analyzed what would be required to retain nuclear power as a significant option for reducing greenhouse gas emissions and meeting growing needs for electricity supply for a global growth scenario.

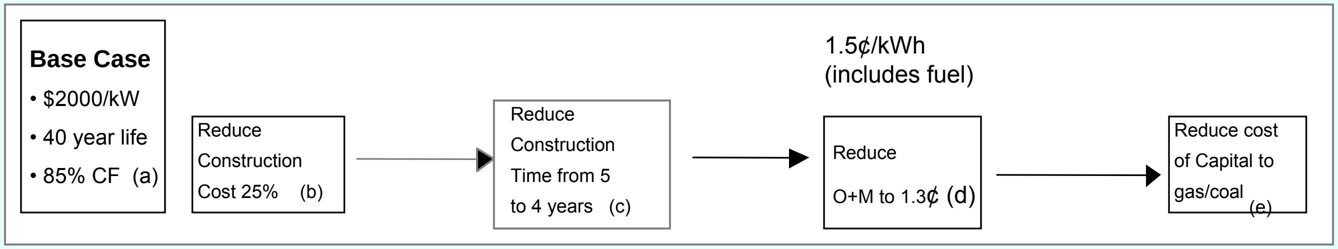
What the Study did NOT do

Analyze priorities among options for reducing carbon emissions - renewable energy sources, carbon sequestration, and increased energy efficiency.

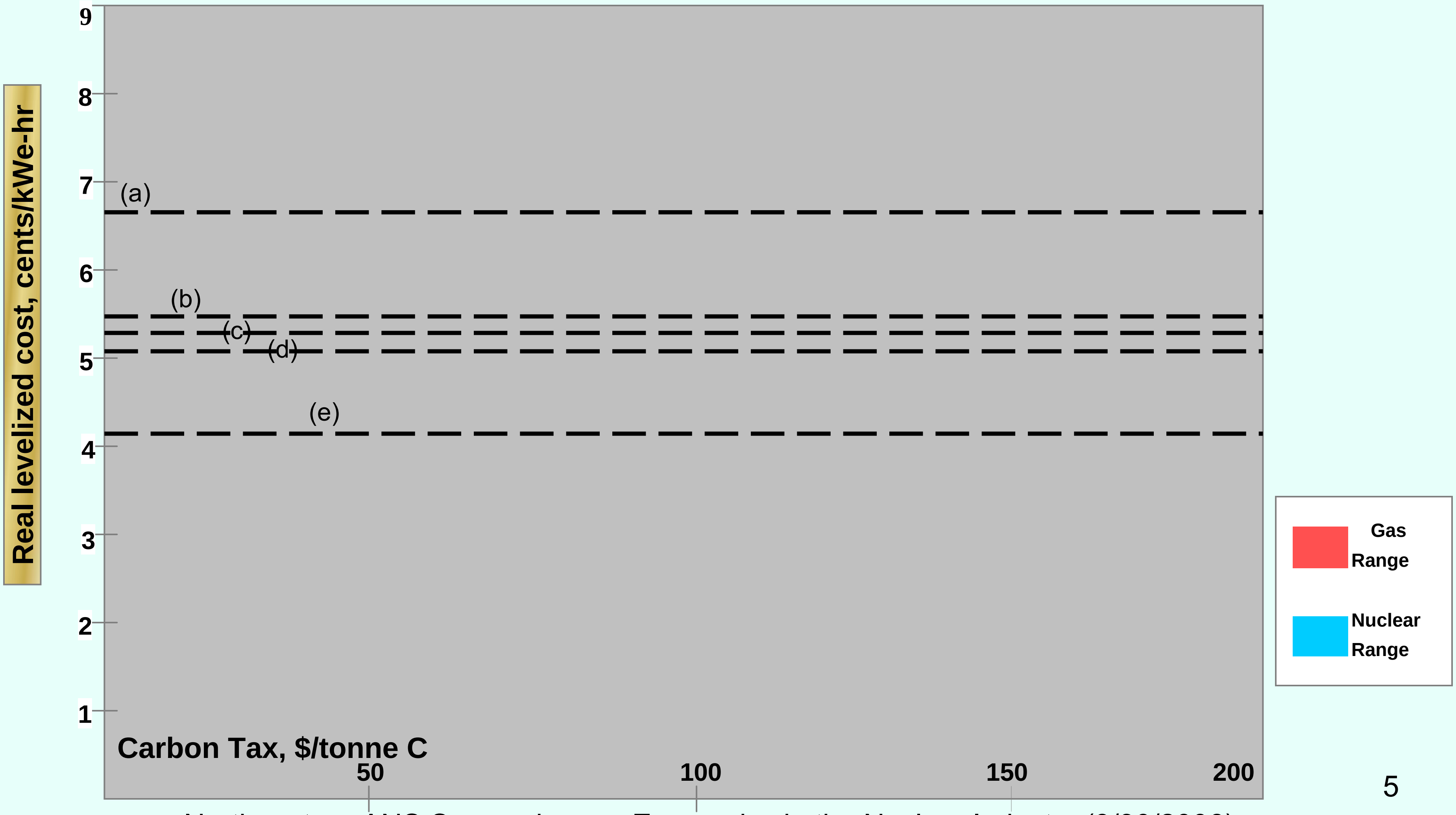
Conclusions on U.S. COE by Generation Alternatives (7/03)

- Nuclear power is not now cost competitive with coal or natural gas.
- Plausible cost reductions by industry can reduce the gap.

MIT Study Results



	Nuclear	Gas
Equity/Debt	50/50%	40/60%
Equity (nominal net of income tax)	15%	12%
Debt (Nominal)	8%	8%
Inflation	3%	3%
Income Tax Rate (after expenses, interest + tax depreciation)	38%	38%



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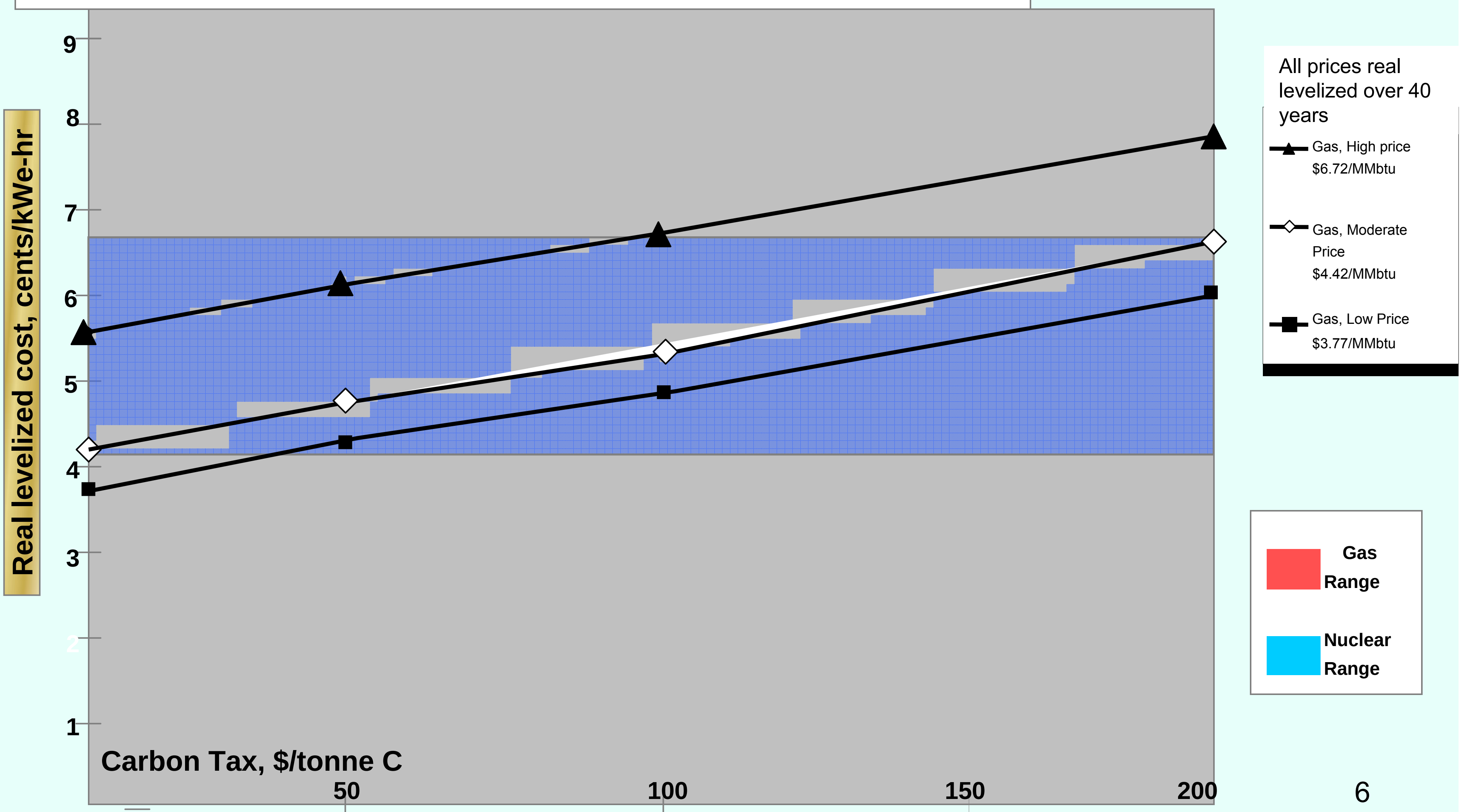
Base Case
- $2000/kW
- 40 year life
- 85% CF (a)

Reduce Construction Cost 25% → Reduce Construction Time from 5 to 4 years → Reduce O+M to 1.3¢ → Reduce cost of Capital to gas/coal

1.5¢/kWh (includes fuel)



COE Issues

- Overnight Capital Cost
- Financing Model
- O & M Cost
- Plant Size
- Fuel Cycle Cost

Overnight Capital Cost

(From Appendix to Chapter 5, MIT Study)

		$ Year	Construction Time Years	Financing	Income Tax	Contingen-cy
USEIA (Jan 03)	Reference Case $2044/kWe in 2010 $1906/kWe in 2025	2001	5		✓	✓
	Advanced Cost Case $1535/kWe in 2012 $1228/kWe in 2025	2001	5		✓	✓
DOE – 2010 Roadmap (Oct 01)	$1000 - 1600/kWe	2000	4.5			
NEA (2001)	USA $1831/kWe	2002	4			✓
	OECD $ 1831 - 2737/kWe	2001	4-9			
FINLAND	$1600/kWe	2002	5	100% Debt at 5% Real Interest	None	
JAPAN	Onagawa 3 (BWR) - $ 2409/kWe K-K 6 (ABWR) - $2020/kWe K-K 7 (ABWR) - $1790/kWe	2002				
KOREA	Yonggwang 5 + 6 - (KSNP-PWRs) $1800/kWe	2002		100% Debt		
BROWN'S FERRY (Restart)	$ 1280/kWe	2002		100% Debt at 80 basis points above 10 yr Treasury	None	
SEABROOK (Sale)	$ 730/kWe	2002		Plus $25.6MM for components and $61.9MM for fuel		

Overnight Capital Cost
(post MIT report 7/03)

1) Univ. of Chicago (8/04) $1200-$1500/kWe
   - ABWR & AP 1000/SWR 1000 + $300/kWe FOAK

2) French DIDEME (12/03)/E. Proust (5/05) $1283 €/kWe

3) J. Turnage (UniStar) (1/06) $1998/kWe
   - Return on equity 15%
   - Equity 20%/Debt 80%

4) R. Matzie (Westinghouse) (3/06) $1400-1600/kWe
   - Twin 1090 MWe units

COE Issues (cont.)

Finance model

- US – distinguishes between equity and debt (different costs & loan payback period)
- French – uniform discount rate (real Weighted Average Cost of Capital [WACC] before tax)

O & M assumption

- US – 2nd best operating plant quartile (base case)
- France – EPR projected gains in availability, rating, cost performance

Financing Assumptions and Technical-Economic Parameters Adopted for Nuclear Power Plant Economic Studies (Proust 2005)

Nuclear Power Plants		MIT		DIDEME
		base case	with optimistic but plausible cost reductions	Series of 10 EPR units incl. FOAK
Overnight Capital Cost	$ or €/kWe	2000	1500	1283
Construction Time		5 years	4 years	57 months, but 1st: 67 months
Capacity factor		85%		88.9%
Fuel cost, incl. Waste fee	$ or €/MWh	5.9		4.4
O&M fixed cost (*)	$ or €/kWe	83		50.9
Cost of Capital (real, *weighted average CoC before tax*, or discount rate)		*12%*	*8.5%*	8%
Inflation rate		3 %		
Equity share		50%	40%	
Debt cost nominal		8 %		
Equity cost nominal		15%	12%	
Debt Term (years)		10		
Corporate Income Tax rate		38 %		
Plant Economic Lifetime	Years	40		60
Levelised Cost of Electricity (LCOE)	**$ or €/MWh**	**67**	**44**	**28.4**
Fossil-Fuel fired Plants				
Coal plant LCOE	**$ or €/MWh**	**42**		**32 to 34**
CCGT LCOE	**$ or €/MWh**	**38 to 56**		**35**

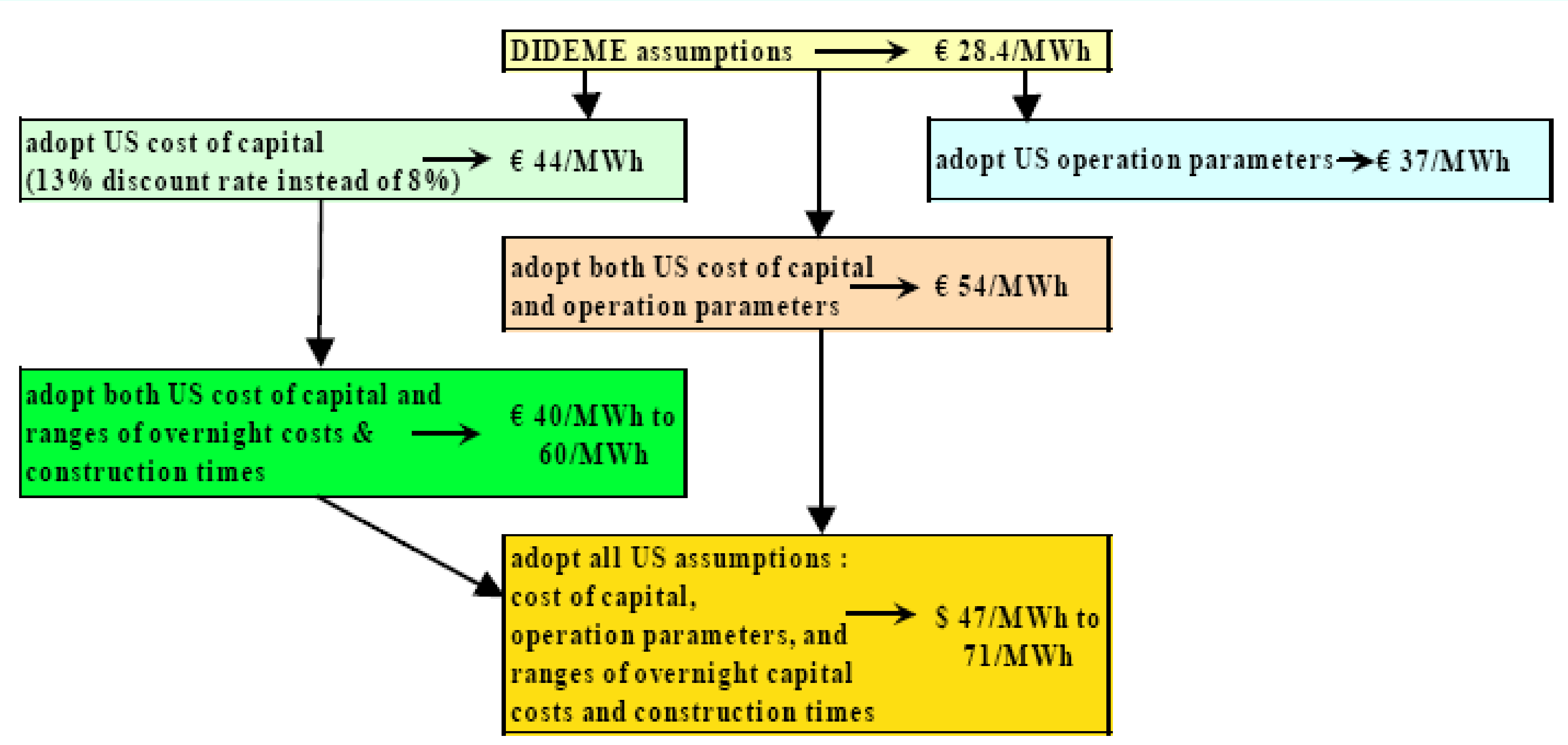
(*) including incremental capital expenses

Financing Assumptions and Technical-Economic Parameters Adopted for Nuclear Power Plant Economic Studies (Proust 2005)

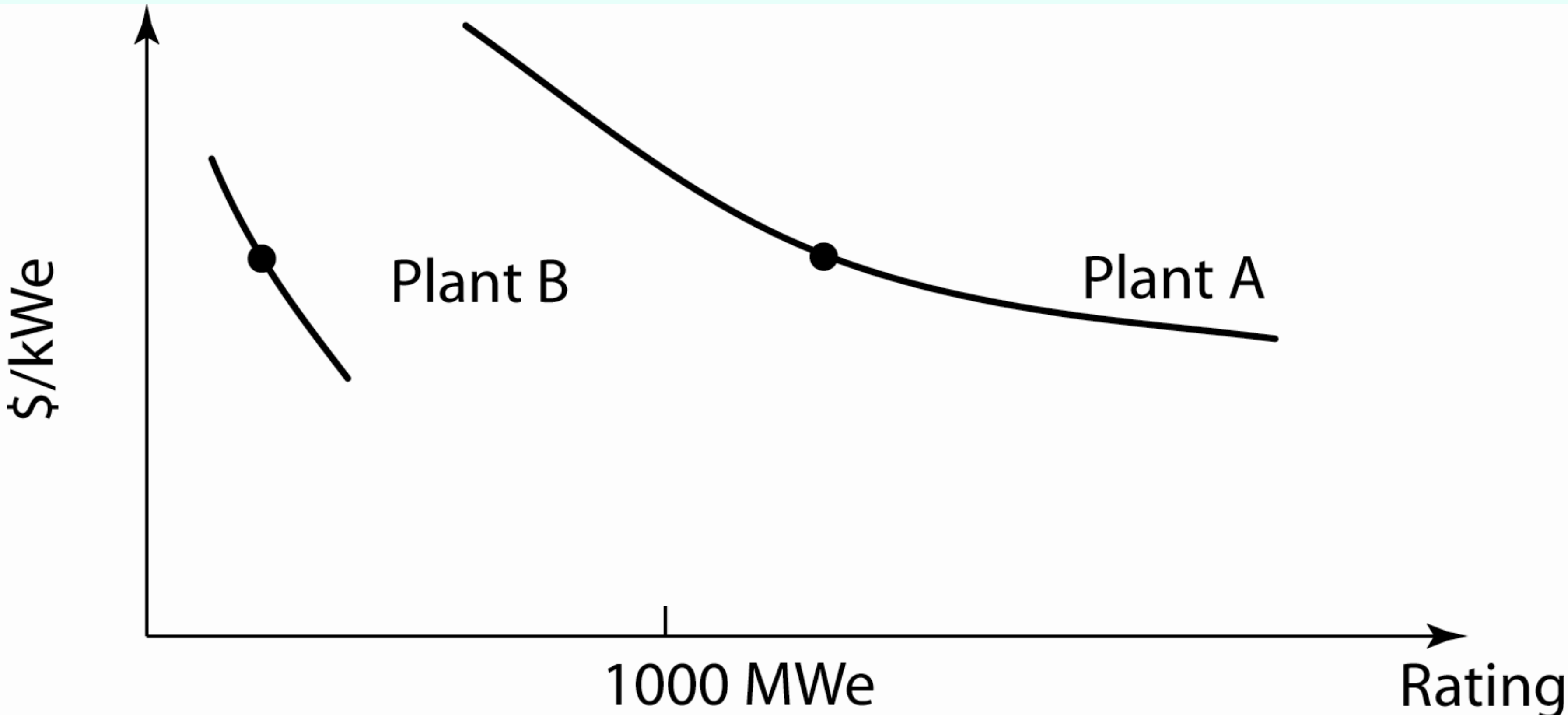
Nuclear Power Plants	MIT		Univ. Of Chicago			DIDEME
	base case	with optimistic but plausible cost reductions	first new build: already built overseas	first new build: FOAK (1)	4th plant after FOAK	Series of 10 EPR units incl. FOAK
Overnight Capital Cost $ or €/kWe	2000	1500	1200	1200 to 1500 + 300 (#)	1200 to 1500 - 6 % (£)	1283
Construction Time	5 years	4 years	7 years *(5 years)*		5 years	57 months, but 1^{st}: 67 months
Capacity factor	85%		85%			88.9%
Fuel cost, incl. Waste fee $ or €/MWh	5.9		5.35			4.4
Fuel cost real escalation rate	0.5%		0.0%			0.0%
O&M fixed cost (*) $ or €/kWe	83		81			50.9
O&M variable cost $ or €/MWh	0.47		2.1			1,2
O&M cost real escalation rate	1.0%		0.0%			0.0%
Dismantling $ or €/kWe	350		350			250
Cost of Capital (real, *weighted average CoC before tax*, or discount rate)	*12%*	*8.5%*	*13%*		*8%*	8%
Inflation rate	3 %		3%			
Equity share	50%	40%	50%		40%	
Debt cost nominal	8 %		10%		7 %	
Equity cost nominal	15%	12%	15%		12 %	
Debt Term (years)	10		15			
Corporate Income Tax rate	38 %		38 %			
Plant Economic Lifetime Years	40		40			60
Levelised Cost of Electricity (LCOE) $ or €/MWh	**67**	**44**	**53** *(47)*	**62** *(54)* **to 71** *(62)*	**34 to 38**	**28.4**
Fossil-Fuel fired Plants						
Coal plant LCOE $ or €/MWh	**42**		**33 to 41**			**32 to 34**
CCGT LCOE $ or €/MWh	**38 to 56**		**35 to 45**			**35**

(1) FOAK overnight cost : AP 1000 assumed at 1200 + 300 $/kWe; SWR 1000 assumed at 1500 + 300 $/kWe
(#) for FOAK plants, $300/kWe are added to account for FOAK engineering costs
(£) learning effects assumed to reduce the overnight capital cost of the 5th plant by 6% compared to the first plant
(*) including incremental capital expenses

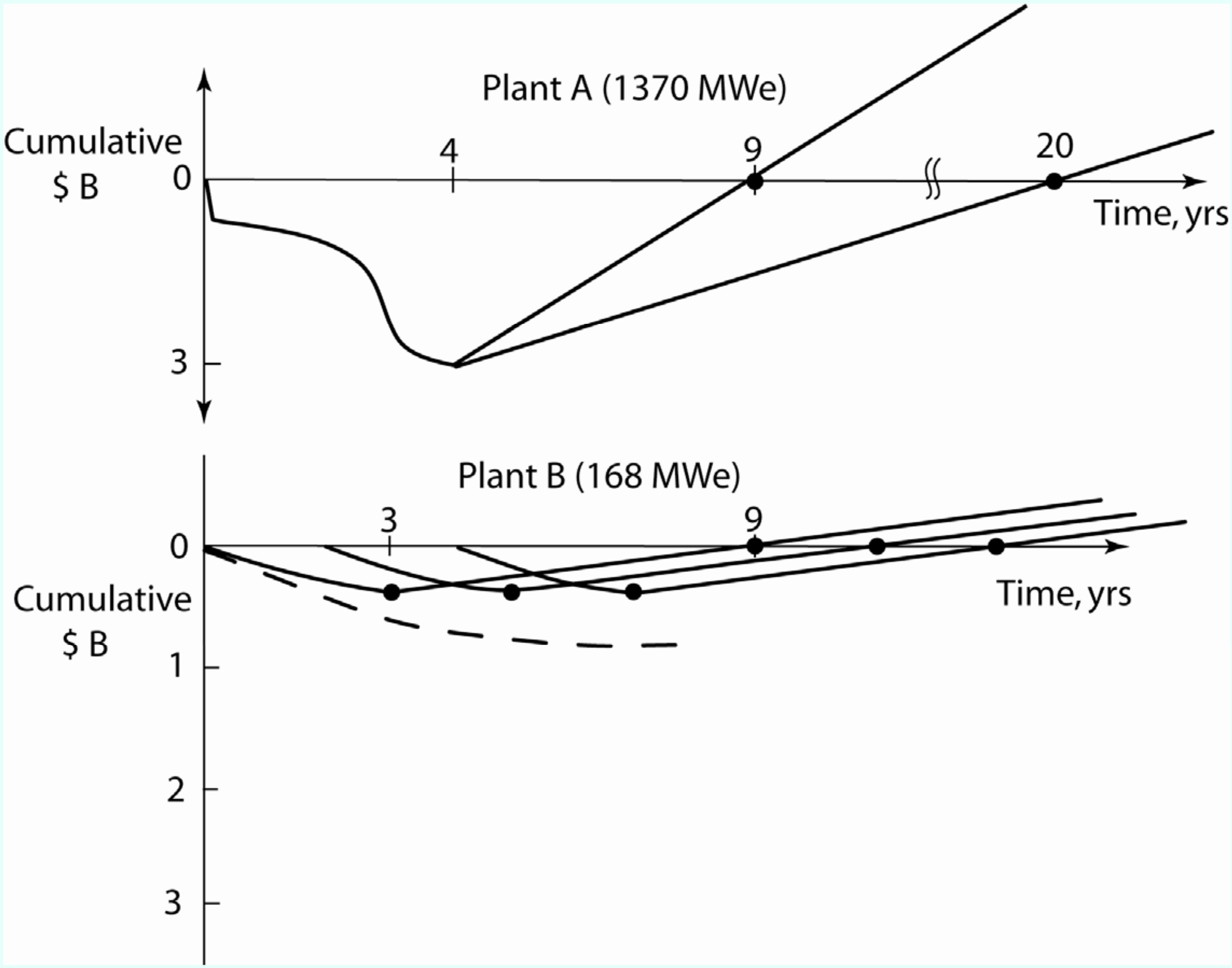
Explaining how to go from the nuclear MWh cost found by the French DIDEME study to the cost range given in the University of Chicago 2004 economic study (Proust, 2005)



Plant Size



Capital Flow



Fuel Cycle Cost
Once-Through vs Single MOX Recycle

1. Single Owner Cost [MIT 7/03]

   Once Through (UOX) 0.515¢/kWh(e) [0.643 OECD/NEA (1994)]

   Single MOX Recycle 2.24¢/kWh(e) [0.680 OECD/NEA (1994)]

   ΔFCC% = 335% MIT [5% OECD/NEA]

   ΔCOE% = 43% MIT [0.9% OECD/NEA]

   where $COE_{UOX} \equiv 4$¢/kWh(e)

2. World (Entire Fleet) Cost [MIT 7/03]

   $FCC_{FLEET} = FCC_{UOX}$ [% Fleet UOX] + FCC_{MOX} [% Fleet MOX]

FLEET	1500 MWe
UOX	1260 MWe
MOX	240 MWe

   0.791 ¢/kWh(e) $\Leftarrow$ 0.515 [0.84] + 2.24 [0.16]

   ΔFCC% = 53%

   ΔCOE% = 69%

Fuel Cycle Cost [MIT 7/03]

	SINGLE OWNER	WORLD (FLEET)
ΔFCC%	+335%	+53%
ΔCOE%	+43%	+6.9%

Assume: COE_{UOX} 4¢/kWh(e)

FLEET 1500 MWe (operating on single MOX recycle)

UOX 1260 MWe

MOX 240 MWe

Comparison of Cost for Once-Through and Recycle Process Steps (MIT 7/03)

Cost Component	Unit	Estimated Cost (lower bound – nominal – upper bound)			
		OECD/NEA[1] (2002)	DOE GEN-IV[2]	Fetter, Bunn, Holdren[3]	Our Best Guess
Ore Purchase	$/kg	20-30-40	20-30-80	33	30
Conversion	$/kg	3-5-7	3-5-8	4-6-8	8
Enrichment	$/kg SWU	50-80-110	50-80-120	50-100-150	100
UOX fabrication	$/kgIHM	200-250-300	200-250-350	150-250-350	275
SF storage and disposal	$/kgIHM	410-530-650	210-410-640	0-150-300 more than HLW	400
UOX reprocessing	$/kgIHM	700-800-900	500-800-1100	500-1000-1600	1000
MOX reprocessing	$/kgIHM	700-800-900	500-800-1100	-	-
HLW storage and disposal	$/kgIHM	63-72-81	80-200-310	0-150-300 less than SF	300
MOX fabrication	$/kgIHM	900-1100-1300	600-1100-1750	700-1500-2300	1500

[1] OECD/NEA, “Accelerator-driven Systems and Fast Reactors in Advanced Nuclear Fuel Cycles”, 2002
[2] DOE, “Generation 4 Roadmap - Report of the Fuel Cycle Crosscut Group”, 2001
[3] Fetter, Bunn, Holdren, “The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel”, 1999

Challenges
(from Turnage, 2005)

There remain a number of challenges:

- Rulemaking
- Public perception (how deep?)
- Financing
- Infrastructure
- Qualified labor pool
- Issues with the back end of the fuel cycle

References

1) Coûts de reference de la production électrique (December 2003) DGEMP-DIDEME, Paris, France.
2) Competitiveness Comparison of the Electricity Production Alternatives. (2003) R. Tarjanne, K. Luostarinen. Lappeenranta University of Technology Research Report EN B-156.
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5) The Economic Future of Nuclear Power. A study conducted at the University of Chicago, August 2004.
6) Stricker, L. and J. Leclercq. An Ocean Apart? A comparative review covering production performance, costs and human resources of the US and French nuclear power fleets. in Nuclear Engineering International, December 2004, pp 20-26.
7) Proust, E. Economic Competitiveness of New (3rd Generation) Nuclear Plants: A French and European Perspective. Proceedings of ICAPP 2005, Seoul, Korea, May 15-19, 2005
8) Matzie, R., Personal communication, Feb. 2006
9) Turnage, J., Cambridge Energy Research Associates Week, Houston, Feb. 2006

UniStar Nuclear Business Model

The UniStar Nuclear Business Model provides a compelling investment opportunity. For a fleet of units with a leveraged overnight capital cost of $1,998/kw and a return on equity at risk of 15%, the following take reflects the approximate resulting bus bar cost structure:

Description	2005 $/MWhr
Fuel	$4
Variable O&M	$1
Fixed O&M	$6
Ongoing Capex	$1
Nuclear Decommissioning Trust	$2
Debt Service	$16
Equity Return	$12
Taxes	(12)
Bus-bar Generation Cost	$30

Note:
1) Decommissioning trust contributions based on an assumed NRC minimum of $475 million for a single 1,600MW unit in 2015. Real rate of trust assets return (asset compounded rate of return less inflation rate) – 2.0%.
2) Negative tax cost represents tax benefit. Tax losses/ credits fully monetized when incurred.
3) Debt service levelized using cost of debt. Equity return and taxes levelized using cost of equity.

UniStar Business Model (cont.)

The robustness of the investment opportunity is suggested by the following sensitivity analysis:

Project Variable	Sensitivity Case	Incremental Impact on Bus-bar Cost 2005$/MWh
Overnight Capital Cost	20% increase of overnight capital cost	$5
Operating Costs	20% increase of operating costs	$2
Plant Capacity Factor	5% decrease of net capacity factor	$2
Production Tax Credits	100% loss of Production Tax Credits	$10
Project Leverage	50% debt financing (vs. 80%)	$20
Interest Rates	100bp interest rate increase (6.5%)	$1

Note: 1) Each sensitivity case is considered in isolation from other sensitivity cases.