Update of the MIT (2003) *Future of Nuclear Power* Cost of Electricity Figures

John E. Parsons & Yangbo Du
February 3, 2009
EPPA Seminar

Disparate Estimates of the Cost of Construction

REUTERS

10 August 2007

"NRG Energy has signed Toshiba Corp. to head a $6 billion to $7 billion project to install two reactors in Texas…"

St. Petersburg Times

31 January 2008

"FPL's estimates for [the] two-reactor project run from $12-billion to $18-billion."

$6 billion ÷ (2*1,350MW) = $2,200/kW

$7 billion ÷ (2*1,350MW) = $2,600/kW

$12 billion ÷ (2*1,100MW) = $5,500/kW

$18 billion ÷ (2*1,100MW) = $8,200/kW

Different Estimates Largely Reflects Different Quotation Methods: Illustration

Table 2: Alternative Cost Quotation Methods for Nuclear Power Plants Illustrated with a Hypothetical Example

		[A]	[B]	[C]	[D]	[E]	[F]
[1]	Project Period (relative to start)	-4	-3	-2	-1	0	
[2]	Year	2009	2010	2011	2012	2013	Total
[3]	Construction Schedule as a Fraction of EPC Cost, $2007	10%	25%	31%	25%	10%	100%
[4]	Vendor EPC Overnight Cost, $2007	318	833	1,030	833	318	3,333
[5]	Vendor EPC Cost, Nominal Dollars as Expended @ 3% Inflation	337	911	1,160	966	380	3,753
[6]	Owner's Costs, Nominal Dollars as Expended	67	182	232	193	76	751
[7]	Transmission System Upgrades, Nominal Dollars as Expended				145	57	202
[8]	Total Cost, excl. Capital Recovery Charge, Nominal Dollars as Expended	405	1,093	1,391	1,304	513	4,706
[9]	Capital Recovery Charge @ 11.5%		47	178	358	549	1,131
[10]	Total Cost, incl. Capital Recovery Charge	405	1,139	1,569	1,662	1,062	5,837
[11]	Total Cost, incl. Capital Recovery Charge, Cumulative	405	1,544	3,113	4,775	5,837	
[12]	Total Outlay, Nominal Dollars as Expended	405	1,093	1,391	1,159	456	4,504
[13]	Total Cost (incl. capital charge), $2013	626	1,515	1,730	1,292	456	5,619
[14]	Overnight Cost, $2007	382	1,000	1,236	1,000	382	4,000
[15]	Overnight Cost, $2013	456	1,194	1,476	1,194	456	4,776

Different Estimates Largely Reflects Different Quotation Methods: NRG & FPL

- NRG South Texas Project estimate
  - EPC only; excludes owner's costs.
  - Overnight cost, 2006 dollars; excludes inflation to dates of build.

- FPL Turkey Point estimate
  - Includes transmission system upgrades needed independent of the plant built.
  - Includes inflation to the completion of the build.
  - Includes financing costs (AFUDC).

- Consistent basis:
  - Overnight cost, 2007$, exclusive of transmission & financing.
  - NRG: $3,480/kW
  - FPL: $3,530/kW

Comparison of 5 Nuclear Build Proposals in the US

Table 4: Overnight Costs for Some Proposed Nuclear Plants in the US

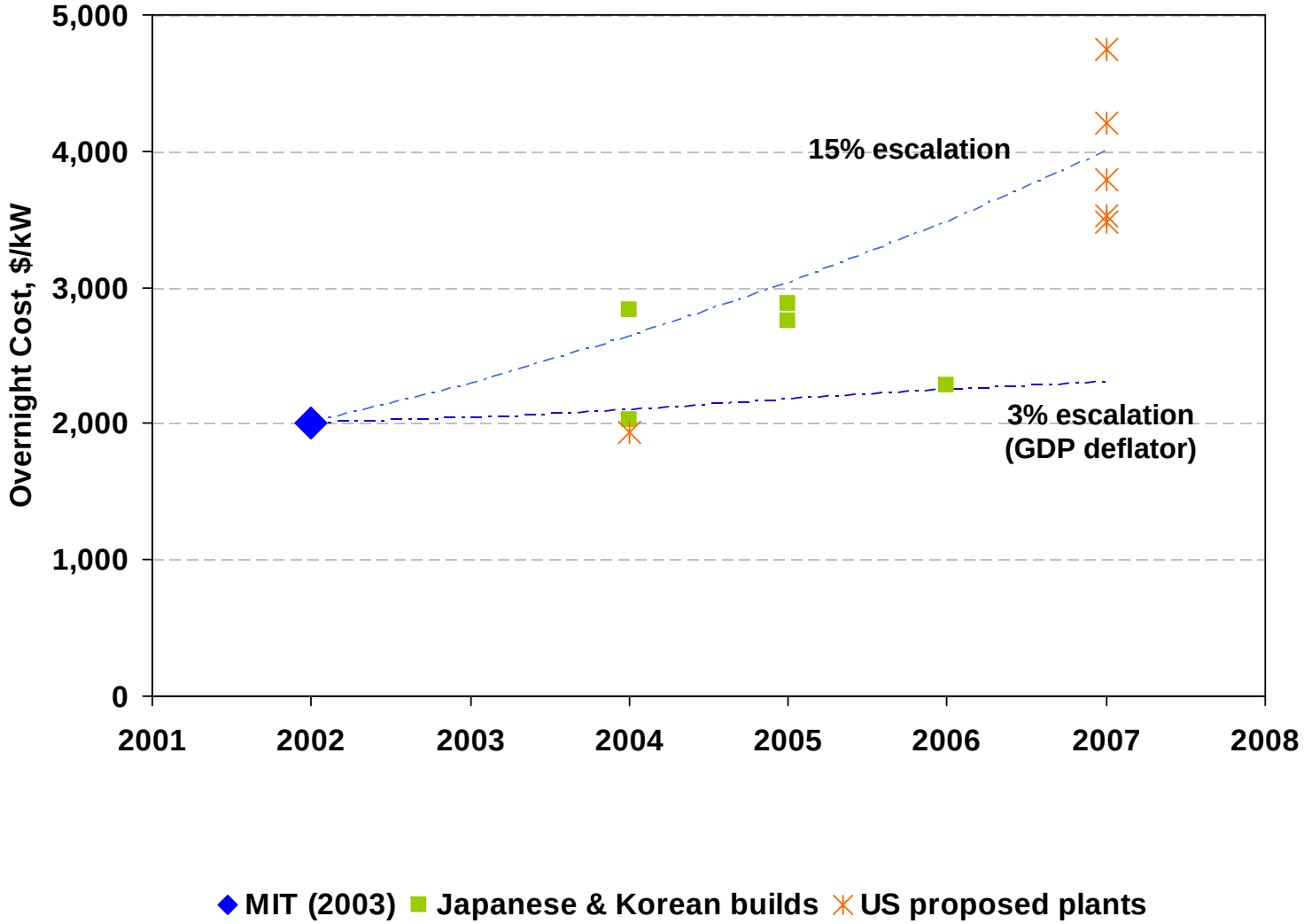
	Owner	Name of Plant	Design	Capacity MW	Projected Commercial Operation Date	Overnight Cost US 2007 $/kW
	[A]	[B]	[C]	[D]	[E]	[F]
[1]	TVA study	Bellefonte	ABWR	1,371	N/A	2,930
[2]	FPL	Turkey Point 5 & 6	ESBWR	3,040	2018-2020	3,530
[3]	Progress Energy	Levy County 1 & 2	AP1000	2,212	2016-2017	4,206
[4]	SCEG/Santee-Cooper	V.C. Summer 2 & 3	AP1000	2,234	2016-2019	3,787
[5]	Southern	Plant Vogtle 2 units	AP1000	2,200	2016-2017	4,745
[6]	NRG	South Texas 3 & 4	ABWR	2,700	2014-2015	3,480

Recent Builds in Japan and Korea

Table 3B: Overnight Costs for Actual Builds in Japan and Korea 2004-2006

						Total Project Cost			Overnight Cost			
	Owner	Name of Plant	Design	Capacity MW	Commercial Operation Date	Domestic Currency millions	PPP Factor	US Equivalent $/kW	Overnight Cost Factor	US various yrs $/kW	Inflation Factor	US 2007 $/kW
	[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]
[7]	Chubu Elec	Hamaoka-5	ABWR	1,325	2004	360	134	2,023	90%	1,820	1.52	2,759
[8]	Tohoku Elec	Higashidori-1	BWR	1,067	2005	390	130	2,821	90%	2,539	1.32	3,351
[9]	Hokuriku Elec	Shika-2	ABWR	1,304	2006	370	124	2,280	90%	2,052	1.15	2,357
[10]	KHNP	Ulchin-5	OPR	995	2004	2,236	794	2,830	78%	2,207	1.52	3,346
[11]	KHNP	Ulchin-6	OPR	994	2005	2,234	789	2,849	78%	2,222	1.32	2,932

Overnight Cost Summary: Nuclear

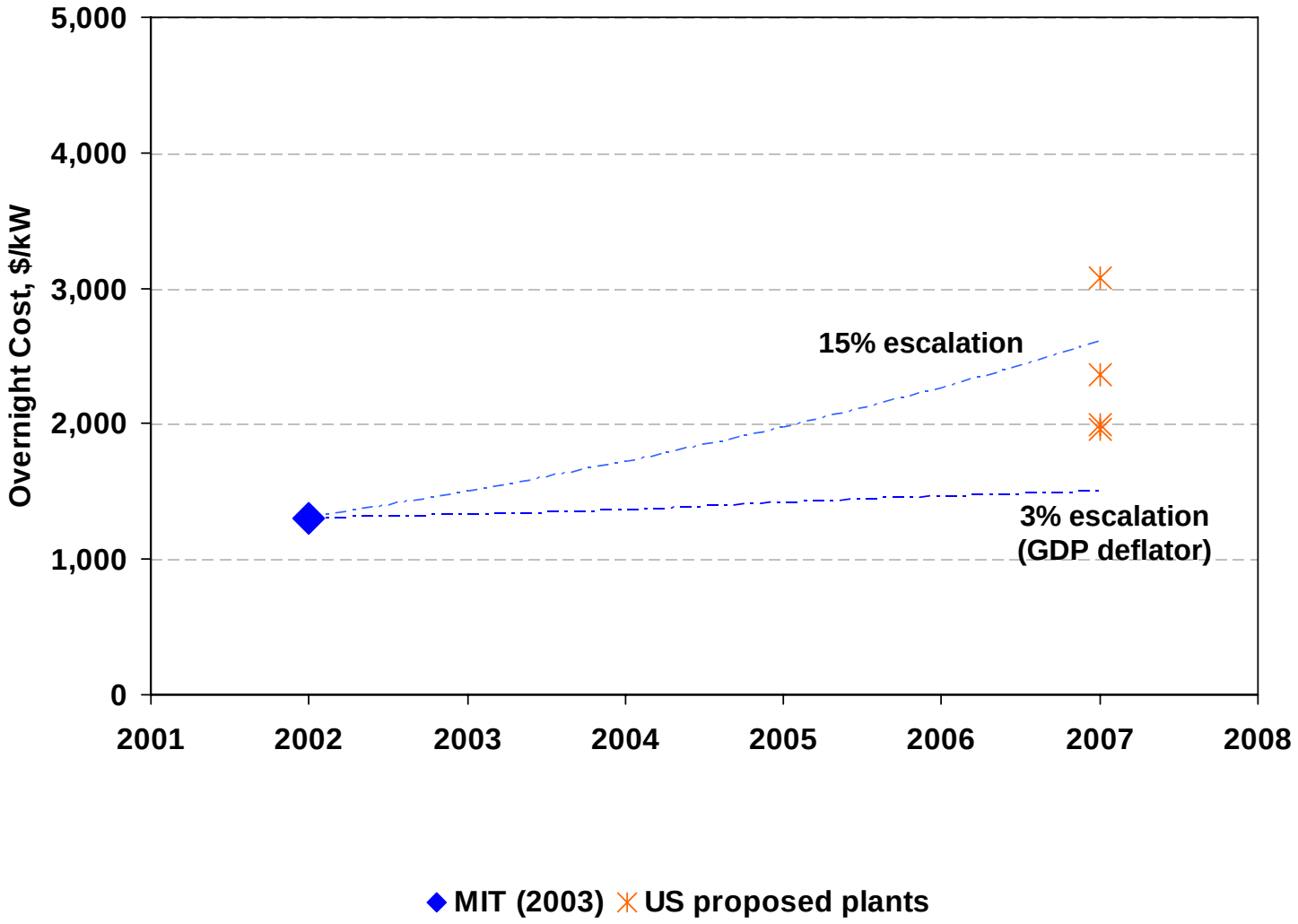


Comparison of 4 Coal Build Proposals in the US

Table 7: Overnight Costs for Some Planned Coal Plants in the US

	Owner	Name of Plant	Design	Fuel	Capacity MW	Projected Commercial Operation Date	Overnight Cost US 2007 $/kW
	[A]	[B]	[C]	[D]	[E]	[F]	[G]
[1]	Florida Power & Light	Glades	USC PC	bituminous	1,960	2013-2014	1,986
[2]	Duke Energy	Cliffside	SC PC	bituminous	800	2012	1,980
[3]	AMP Ohio	Meigs Co.	SC PC	blend	960	2014	3,079
[4]	AEP Swepco	John W. Turk Jr.	USC PC	sub-bituminous	600	2012	2,358

Overnight Cost Summary: Coal



LCOE Assumptions Update

Table 5: Base Case Assumptions and Inputs for the Levelized Cost of Electricity

	Input	Units	Nuclear [A]	Coal [B]	Gas [C]
[1]	Capacity	MW	1,000	1,000	1,000
[2]	Capacity Factor		85%	85%	85%
[3]	Heat rate	Btu/kWh	10,400	8,870	6,800
[4]	Overnight Cost	$/kW	4,000	2,300	850
[5]	Incremental capital costs	$/kW/year	40	27	10
[6]	Fixed O&M Costs	$/kW/year	56	24	13
[7]	Variable O&M Costs	mills/kWh	0.42	3.57	0.41
[8]	Fuel Costs	$/mmBtu	0.67	2.60	7.00
[9]	Waste fee	$/kWh	0.001		
[10]	Decommissioning cost	$ million	700		
[11]	Carbon intensity	kg-C/mmBtu		25.8	14.5
[12]	Inflation Rate		3.0%	3.0%	3.0%
[13]	O&M real escalation		1.0%	1.0%	1.0%
[14]	Fuel real escalation		0.5%	0.5%	0.5%
[15]	Tax Rate		37%	37%	37%
[16]	Debt fraction		50%	60%	60%
[17]	Debt rate		8%	8%	8%
[18]	Equity rate		15%	12%	12%
[19]	WACC (weighted avg cost of capital)		10.0%	7.8%	7.8%

LCOE Assumptions Update: Key Variables Changed

Table 5: Base Case Assumptions and Inputs for the Levelized Cost of Electricity

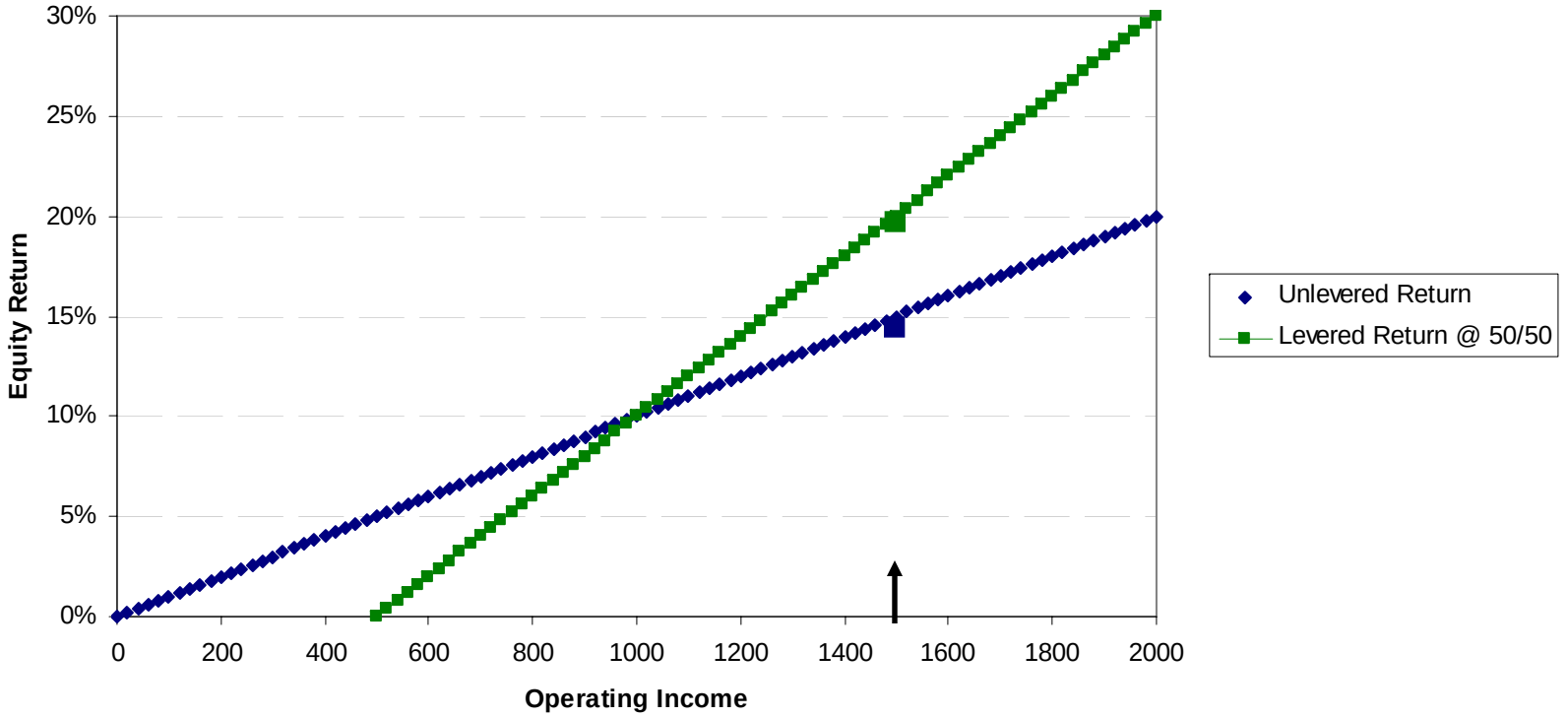
	Input	Units	Nuclear [A]	Coal [B]	Gas [C]
[1]	Capacity	MW	1,000	1,000	1,000
[2]	Capacity Factor		85%	85%	85%
[3]	Heat rate	Btu/kWh	10,400	8,870	6,800
[4]	Overnight Cost	$/kW	4,000	2,300	850
[5]	Incremental capital costs	$/kW/year	40	27	10
[6]	Fixed O&M Costs	$/kW/year	56	24	13
[7]	Variable O&M Costs	mills/kWh	0.42	3.57	0.41
[8]	Fuel Costs	$/mmBtu	0.67	2.60	7.00
[9]	Waste fee	$/kWh	0.001		
[10]	Decommissioning cost	$ million	700		
[11]	Carbon intensity	kg-C/mmBtu		25.8	14.5
[12]	Inflation Rate		3.0%	3.0%	3.0%
[13]	O&M real escalation		1.0%	1.0%	1.0%
[14]	Fuel real escalation		0.5%	0.5%	0.5%
[15]	Tax Rate		37%	37%	37%
[16]	Debt fraction		50%	60%	60%
[17]	Debt rate		8%	8%	8%
[18]	Equity rate		15%	12%	12%
[19]	WACC (weighted avg cost of capital)		10.0%	7.8%	7.8%

LCOE Assumptions Update: Reviewing the Cost of Capital Choices

Table 5: Base Case Assumptions and Inputs for the Levelized Cost of Electricity

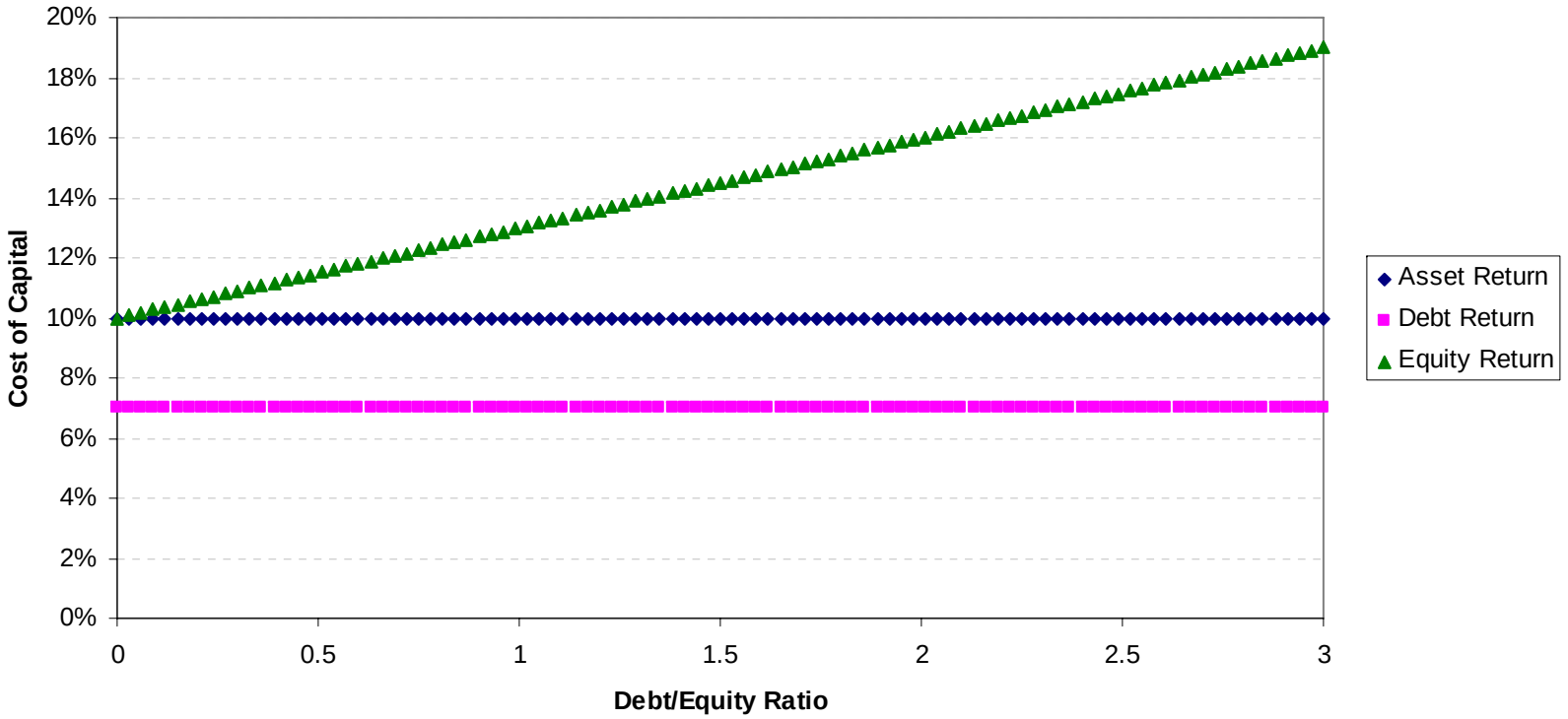
	Input	Units	Nuclear [A]	Coal [B]	Gas [C]
[1]	Capacity	MW	1,000	1,000	1,000
[2]	Capacity Factor		85%	85%	85%
[3]	Heat rate	Btu/kWh	10,400	8,870	6,800
[4]	Overnight Cost	$/kW	4,000	2,300	850
[5]	Incremental capital costs	$/kW/year	40	27	10
[6]	Fixed O&M Costs	$/kW/year	56	24	13
[7]	Variable O&M Costs	mills/kWh	0.42	3.57	0.41
[8]	Fuel Costs	$/mmBtu	0.67	2.60	7.00
[9]	Waste fee	$/kWh	0.001		
[10]	Decommissioning cost	$ million	700		
[11]	Carbon intensity	kg-C/mmBtu		25.8	14.5
[12]	Inflation Rate		3.0%	3.0%	3.0%
[13]	O&M real escalation		1.0%	1.0%	1.0%
[14]	Fuel real escalation		0.5%	0.5%	0.5%
[15]	Tax Rate		37%	37%	37%
[16]	Debt fraction		50%	60%	60%
[17]	Debt rate		8%	8%	8%
[18]	Equity rate		15%	12%	12%
[19]	WACC (weighted avg cost of capital)		10.0%	7.8%	7.8%
[20]	Construction Schedule				

Cost of Capital Theory – Leverage & Equity Returns



- Brealey, Myers & Allen, Table 17.2, MacBeth Spot Removers
- Total Capital = $10,000.
- Expected Operating Income = $1,500, which is a 15% asset return. For the unlevered firm, this is also a 15% equity return.
- Debt = $5,000. At 10% interest rate, interest = $500. Expected equity income is $1,000, which is a 20% return on Equity=$5,000.
- Equity captures the return not paid to debt. But equity is also riskier.

Cost of Capital Theory – the MM Theorem



- What happens: Asset return is given. Debt rate is given. Equity rate is derived. Different debt/equity ratios imply different equity rates.
- What we observe: Debt rates, equity rates and a debt/equity ratio… we back out an implied asset rate.
- Mistake we make: (1) Fix the debt and equity rates, then change the leverage ratio.
- Mistake we make: (2) Use book values for the debt/equity ratio.

Alternative Cash Flow Valuation Methods

- Equity Cash Flow method
  - Equity after-tax cash flow.
  - Tax shield from debt explicitly adds to the equity cash flows.
  - Apply the equity discount rate, R_e.
- Adjusted Present Value method
  - Project unlevered after-tax cash flow. Ignore the tax shielf from debt.
  - Apply the asset discount rate, R_a.
  - Separately calculate the value of the debt tax shield.
  - Add the value of the unlevered project and the value of the tax shield.
- WACC
  - Project unlevered after-tax cash flow.
  - No accounting for debt in the cash flows. Apparent tax burden is too large.
  - Apply the Weighted Average Cost of Capital.
    - $WACC = R_e (E/V) + R_d (D/V) (1-t)$
  - The value of the debt tax shields are embedded in setting the discount rate lower by the (1-t) factor.

Alternative Cash Flow Valuation Methods (cont.)

- Ideally, All 3 Methods Give the Same Result.
- The ideal assumptions require that
  - The debt profile through time is the same for all three.
    - WACC assumes a constant debt/equity ratio in market value terms.
    - The other 2 methods usually fix a debt schedule in nominal terms, and the market value of equity is derived, so that the market value ratio may not match what was assumed for the WACC.
    - In reality, debt profiles are seldom fixed, but adjust to contingencies, albeit with frictions.
  - The equity discount rate is consistent with the project discount rate is consistent with the WACC.
    - Since the market value debt/equity ratio is changing through time, the equity discount rate is changing, and it is difficult to assure the value chosen is correct.

LCOE Assumptions Update: Reviewing the Cost of Capital Choices

Table 5: Base Case Assumptions and Inputs for the Levelized Cost of Electricity

	Input	Units	Nuclear [A]	Coal [B]	Gas [C]
[1]	Capacity	MW	1,000	1,000	1,000
[2]	Capacity Factor		85%	85%	85%
[3]	Heat rate	Btu/kWh	10,400	8,870	6,800
[4]	Overnight Cost	$/kW	4,000	2,300	850
[5]	Incremental capital costs	$/kW/year	40	27	10
[6]	Fixed O&M Costs	$/kW/year	56	24	13
[7]	Variable O&M Costs	mills/kWh	0.42	3.57	0.41
[8]	Fuel Costs	$/mmBtu	0.67	2.60	7.00
[9]	Waste fee	$/kWh	0.001		
[10]	Decommissioning cost	$ million	700		
[11]	Carbon intensity	kg-C/mmBtu		25.8	14.5
[12]	Inflation Rate		3.0%	3.0%	3.0%
[13]	O&M real escalation		1.0%	1.0%	1.0%
[14]	Fuel real escalation		0.5%	0.5%	0.5%
[15]	Tax Rate		37%	37%	37%
[16]	Debt fraction		50%	60%	60%
[17]	Debt rate		8%	8%	8%
[18]	Equity rate		15%	12%	12%
[19]	WACC (weighted avg cost of capital)		10.0%	7.8%	7.8%
[20]	Construction Schedule				

Levelized Cost of Electricity

Table 1: Summary of Results

	MIT (2003)				Update			
		LCOE				LCOE		
	Overnight Cost	Base Case	w/ Carbon Charge $25/tCO2	w/ same cost of capital	Overnight Cost	Base Case	w/ Carbon Charge $25/tCO2	w/ same cost of capital
	$2002/kW	2002¢/kWh	2002¢/kWh	2002¢/kWh	$2007/kW	2007¢/kWh	2007¢/kWh	2007¢/kWh
Nuclear	2,000	6.7		5.5	4,000	8.4		6.6
Coal	1,300	4.3	6.4		2,400	6.2	8.3	
Gas	500	4.1	5.1		900	6.5	7.4	

Figure 1: Summary Results for the Levelized Cost of Electricity from Alternative Sources

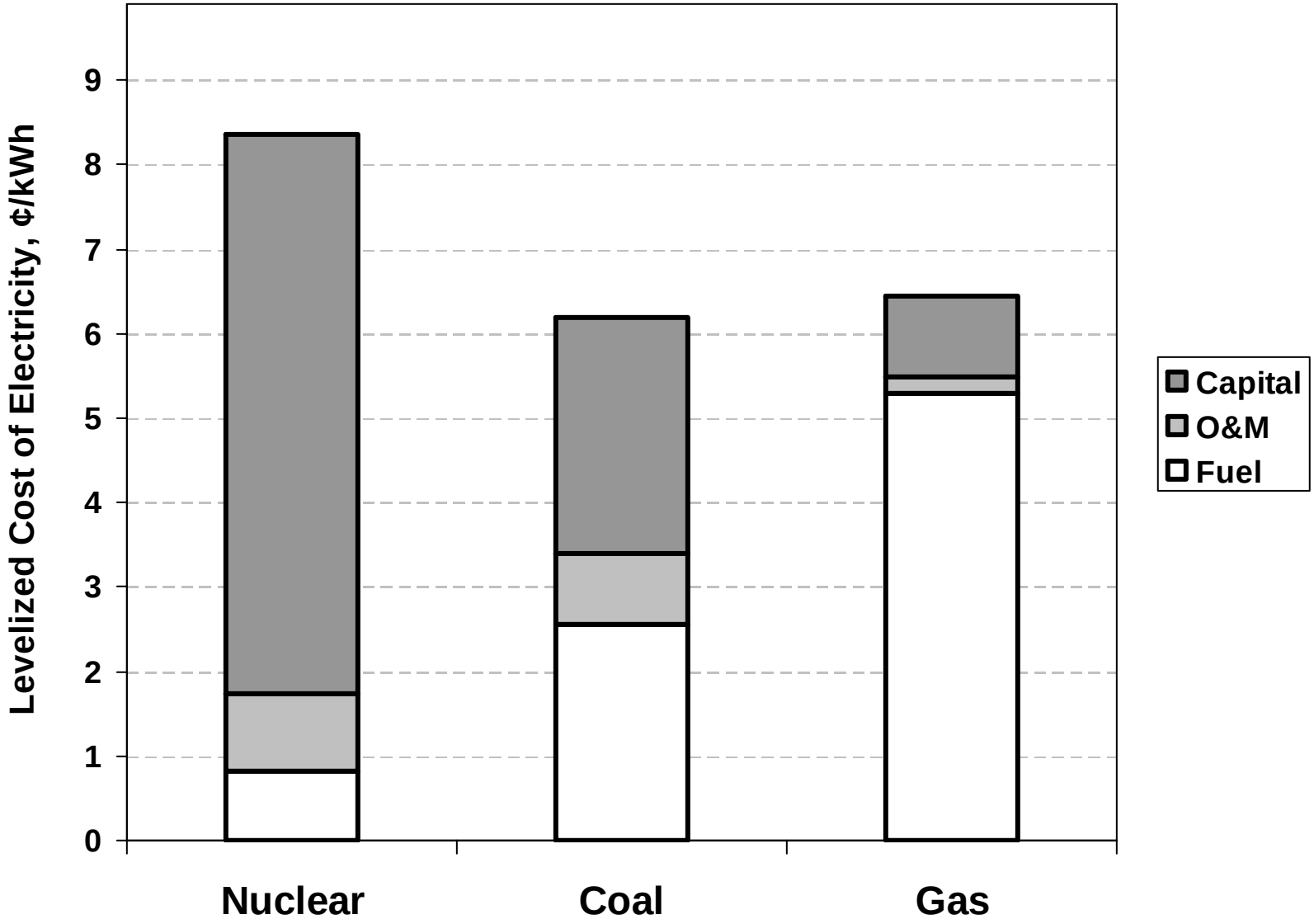


Figure 1: Summary Results for the Levelized Cost of Electricity from Alternative Sources

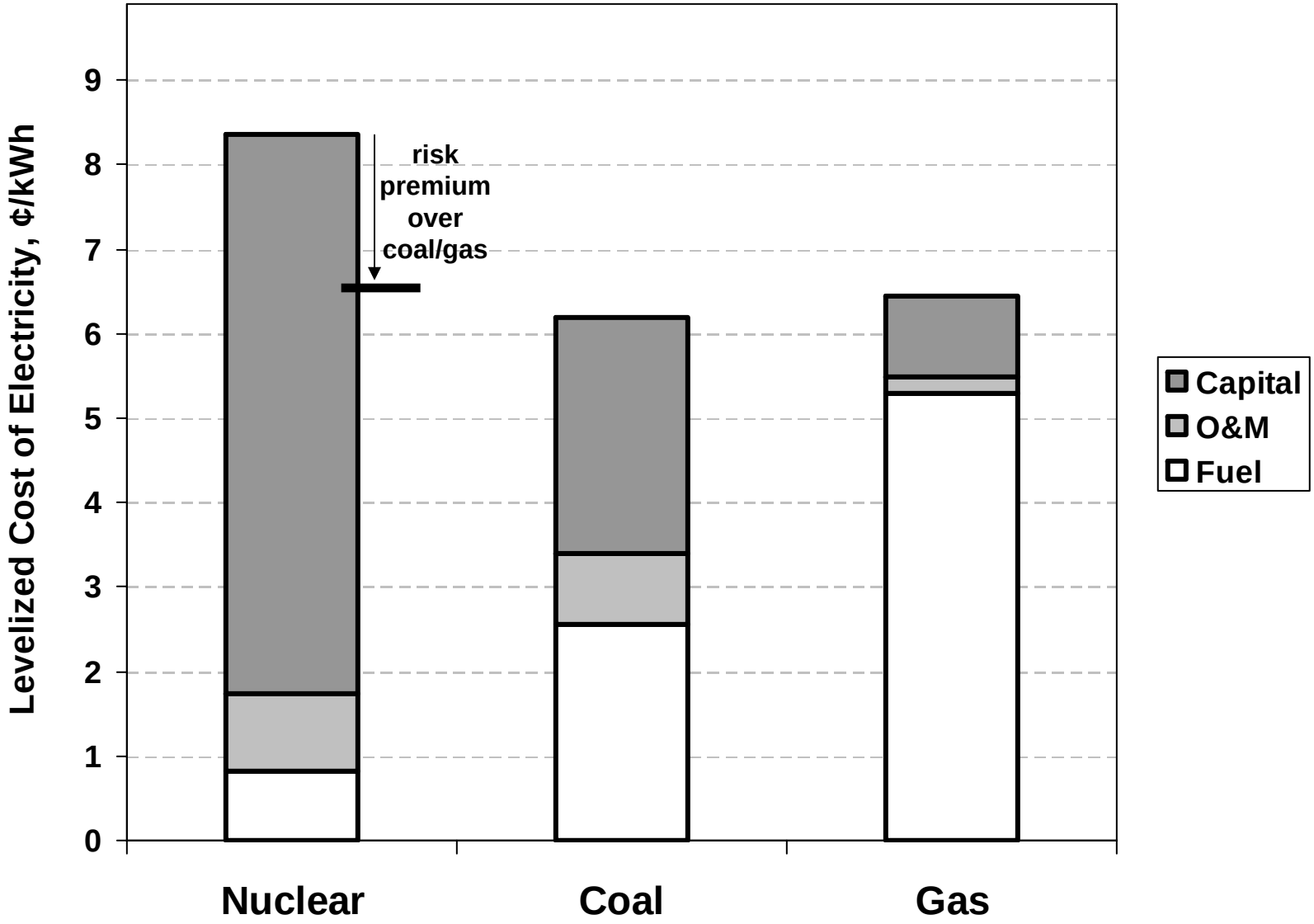
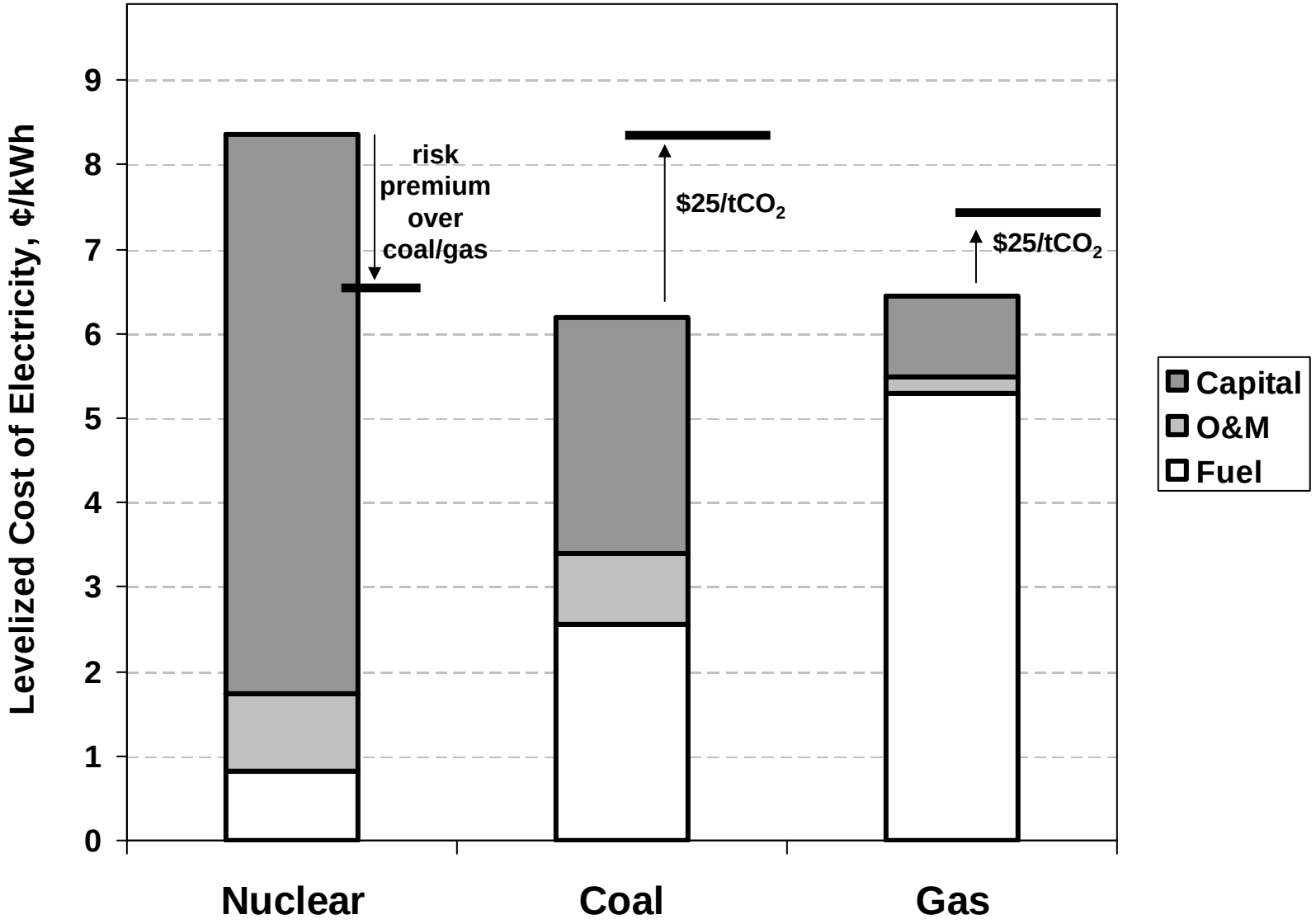


Figure 1: Summary Results for the Levelized Cost of Electricity from Alternative Sources



The End