



TECHNOLOGY AND POLICY  
PROGRAM

# Power Plant Development Options in Abu Dhabi

Application Portfolio  
ESD.71 Engineering Systems Analysis for Design

Kyle Frazier  
December 2007

# Outline

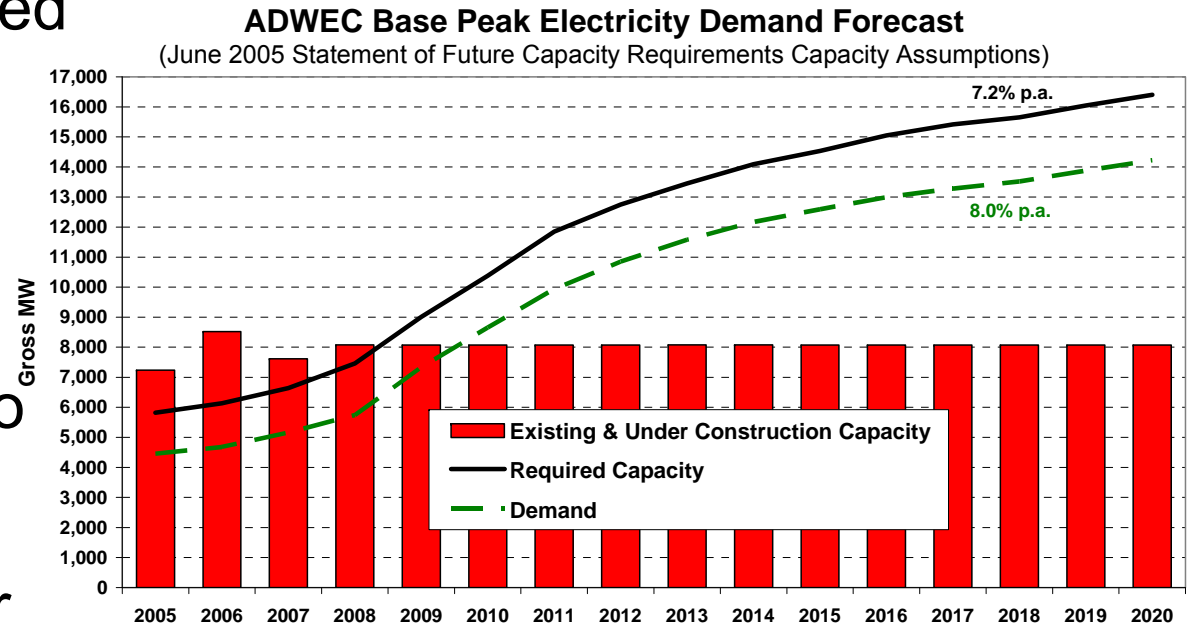
- Introduction and Background
  - Economic & Business Context
  - Identifying Uncertainties
- Defining System Concepts
  - Concept 1 – Fixed Alternative
  - Concept 2 – Phased/Flexible Alternative
- Decision Analysis – Demand Uncertainty
  - Developing the Decision Tree
  - Optimal Actions
- Valuation of Put Option – Concept 1
  - Building the Lattice Model
  - Option Valuation
- Conclusions





# Economic & Business Context

- Projections of sustained economic growth → increasing electricity demand
- Need new electricity generating capacity
- Government turning to privatization of power generation sector
- Opportunities exist for independent (water and) power producers (IPPs/IWPPs)



- 2006 ADWEC Demand Forecast predicts a shortfall in capacity from 2009 onwards



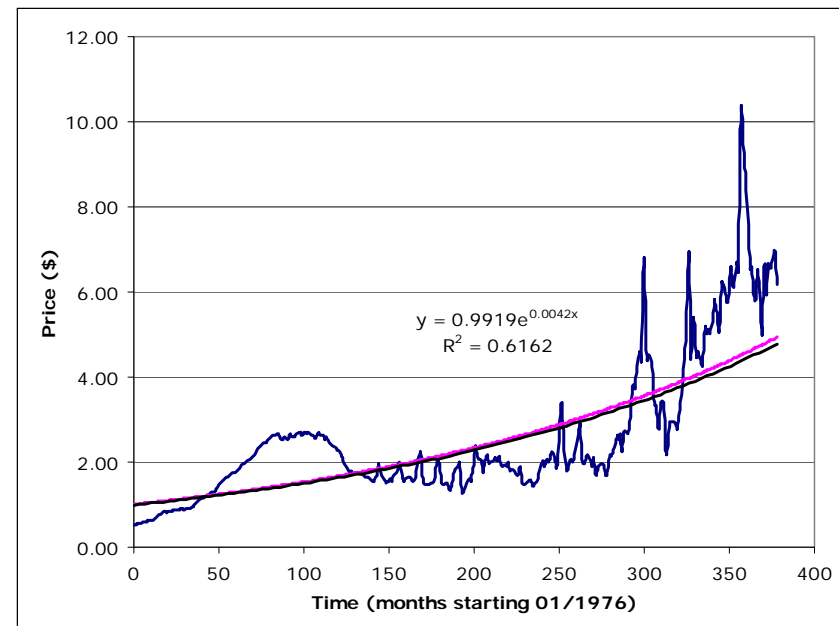
# Identifying Uncertainties

## *Key Sources:*

- fuel prices
- technical change
- privatization and regulation policy shifts
- changes in the industrial or market structure
- shifts in economic/financial policy and capital flow controls
- end-user demand for electric power

## *Quantified Uncertainties:*

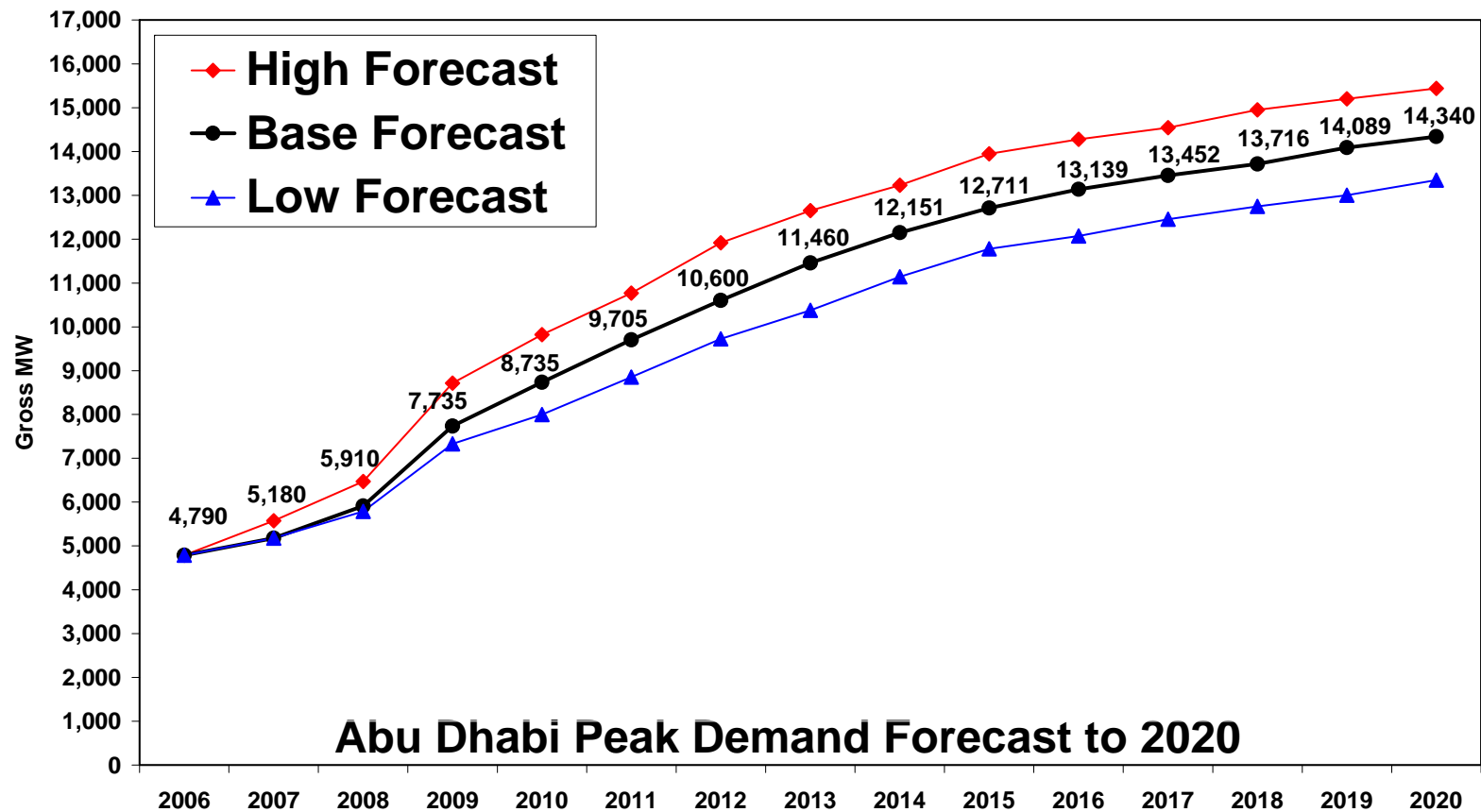
- fuel prices (natural gas)
- demand for electric power generation capacity



**32-Year Natural Gas Wellhead Price History**



# Identifying Uncertainties – Power Demand



- IWPP targets ~ 20% of demand for capacity, or about 3350 gross MWe by 2027



# System Concepts

- Concept 1 – Fixed
  - Single, 3000-MWe capacity, natural gas-fired power plant
  - 20 year analysis; assume plant design live >20 years

Year	0	1	10	11	20
Number of Plants	-	-	-	-	-
NG - Lg (3000 MW)		1	1	1	1
NG - Sm (1000 MW)		0	0	0	0
Solar (500 MW)		0	0	0	0
NG Total Capacity		3000	3000	3000	3000
Solar Total Capacity		0	0	0	0
System Capacity		3000	3000	3000	3000
Demand		1224	2703	2771	3352
Production		1224	2703	2771	3000
Revenue (\$M)		\$232	\$513	\$527	\$570
Variable Cost (\$M)		\$98	\$338	\$360	\$525
Capital Investment (\$M)	\$1,500	\$0	\$0	\$0	\$0
Net value (\$M)	-\$1,500	\$135	\$176	\$166	\$45
Discount Factor @ 9.0%	1.000	1.090	2.367	2.580	5.604
Present Value (\$M)	-\$1,500	\$123	\$74	\$64	\$8
NPV (\$M)		-\$56			



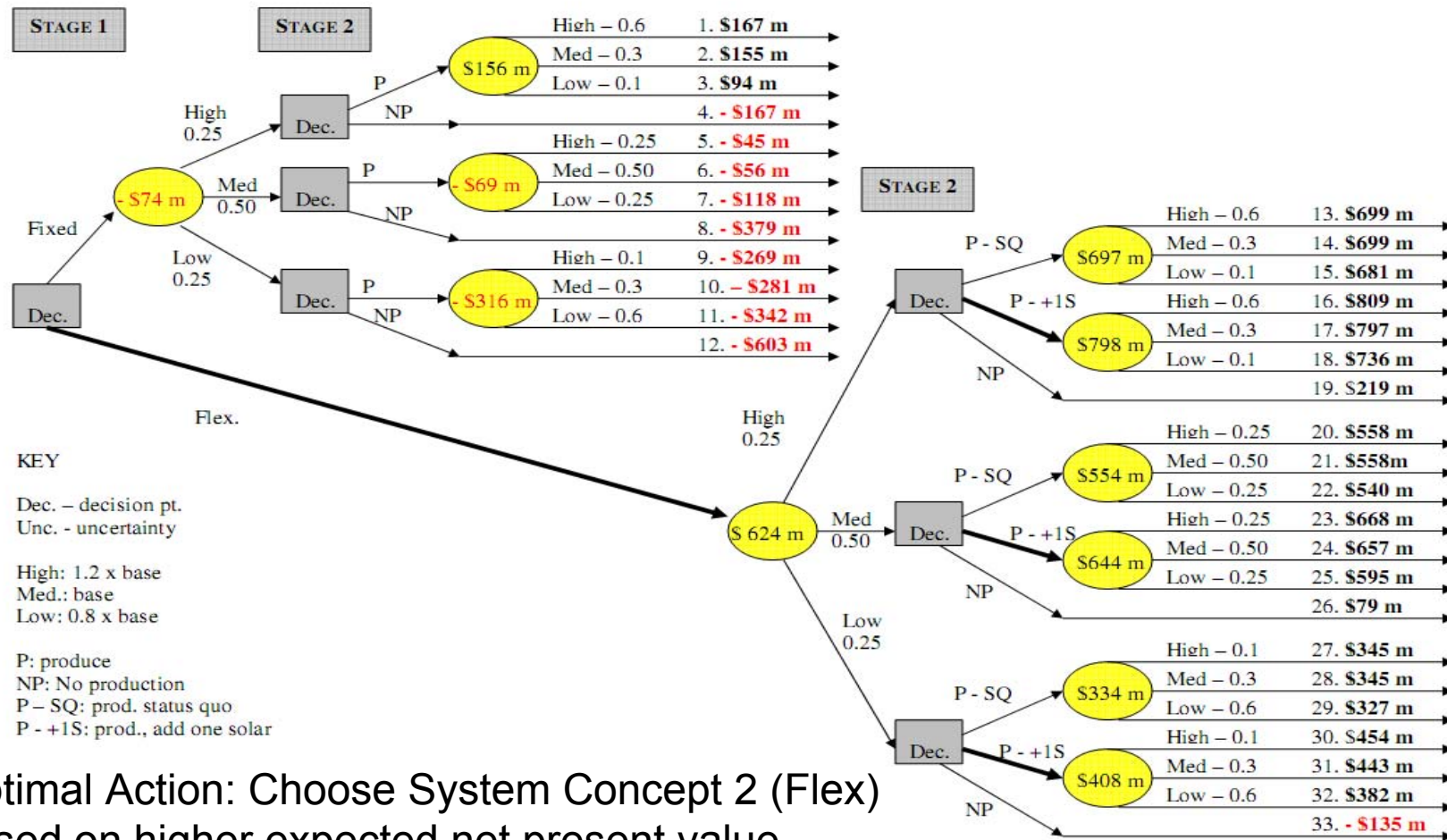
# System Concepts

- Concept 2 – Phased
  - Two 1000-MWe capacity, natural gas-fired power plants and one 500-MWe solar power plant at year 0
  - Option to add second 500-MWe solar plant at year 10
  - 20 year analysis; assume plant design life >20 years

Year	0	1	10	11	20
Number of Plants	-	-	-	-	-
NG - Lg (3000 MW)		0	0	0	0
NG - Sm (1000 MW)		2	2	2	2
Solar (500 MW)		1	1	2	2
NG Total Capacity		2000	2000	2000	2000
Solar Total Capacity		500	500	1000	1000
System Capacity		2500	2500	3000	3000
Demand		1224	2703	2771	3352
Production		1224	2500	2771	3000
Revenue (\$M)		\$232	\$475	\$527	\$570
Variable Cost (\$M)		\$58	\$250	\$230	\$350
Capital Investment (\$M)	\$1,350	\$0	\$350	\$0	\$0
Net value (\$M)	-\$1,350	\$175	-\$125	\$296	\$220
Discount Factor @ 9.0%	1.000	1.090	2.367	2.580	5.604
Present Value (\$M)	-\$1,350	\$160	-\$53	\$115	\$39
NPV (\$M)		\$657			



# Decision Analysis





# Building the Lattice Model

- Uncertainty: price of natural gas
- Analysis method: binomial lattice, dynamic programming approach
- Lattice Parameters:
  - $v = 5.04$  % per year
  - $\sigma = 38.13$  %
  - $u = 1.46419$
  - $d = 0.68297$
  - $p = 0.56609$
  - $\Delta T = 1$  year

FORMULAS FOR PARAMETERS:

$$u = e \exp (\sigma \sqrt{\Delta t})$$

$$d = e \exp (-\sigma \sqrt{\Delta t})$$

$$p = 0.5 + 0.5 (v/\sigma) \sqrt{\Delta t}$$



# Building the Lattice Model

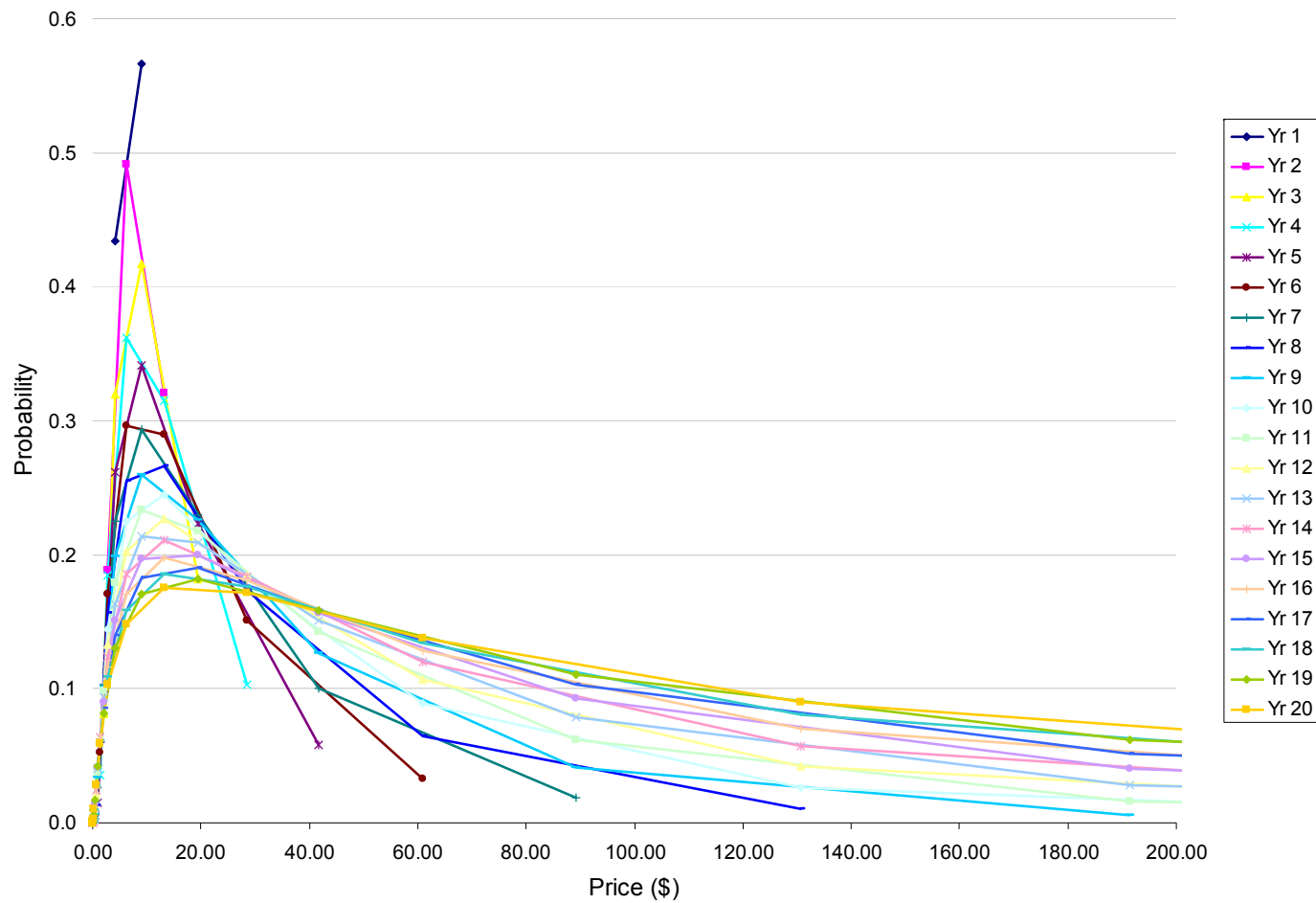
OUTCOME LATTICE																						
Stage/Year																						
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Step	
6.19	9.06	13.27	19.43	28.45	41.66	60.99	89.30	130.76	191.45	280.32	410.44	600.96	879.92	1288.37	1886.42	2762.07	4044.18	5921.44	8670.10	12694.64	20	
	4.23	6.19	9.06	13.27	19.43	28.45	41.66	60.99	89.30	130.76	191.45	280.32	410.44	600.96	879.92	1288.37	1886.42	2762.07	4044.18	5921.44	19	
		2.89	4.23	6.19	9.06	13.27	19.43	28.45	41.66	60.99	89.30	130.76	191.45	280.32	410.44	600.96	879.92	1288.37	1886.42	2762.07	18	
			1.97	2.89	4.23	6.19	9.06	13.27	19.43	28.45	41.66	60.99	89.30	130.76	191.45	280.32	410.44	600.96	879.92	1288.37	17	
				1.35	1.97	2.89	4.23	6.19	9.06	13.27	19.43	28.45	41.66	60.99	89.30	130.76	191.45	280.32	410.44	600.96	16	
					0.92	1.35	1.97	2.89	4.23	6.19	9.06	13.27	19.43	28.45	41.66	60.99	89.30	130.76	191.45	280.32	15	
						0.63	0.92	1.35	1.97	2.89	4.23	6.19	9.06	13.27	19.43	28.45	41.66	60.99	89.30	130.76	14	
							0.43	0.63	0.92	1.35	1.97	2.89	4.23	6.19	9.06	13.27	19.43	28.45	41.66	60.99	13	
								0.29	0.43	0.63	0.92	1.35	1.97	2.89	4.23	6.19	9.06	13.27	19.43	28.45	12	
									0.20	0.29	0.43	0.63	0.92	1.35	1.97	2.89	4.23	6.19	9.06	13.27	11	
										0.14	0.20	0.29	0.43	0.63	0.92	1.35	1.97	2.89	4.23	6.19	10	
											0.09	0.14	0.20	0.29	0.43	0.63	0.92	1.35	1.97	2.89	9	
												0.06	0.09	0.14	0.20	0.29	0.43	0.63	0.92	1.35	8	
													0.04	0.06	0.09	0.14	0.20	0.29	0.43	0.63	7	
														0.03	0.04	0.06	0.09	0.14	0.20	0.29	6	
															0.02	0.03	0.04	0.06	0.09	0.14	5	
																0.01	0.02	0.03	0.04	0.06	4	
																	0.01	0.01	0.02	0.03	3	
																		0.01	0.01	0.01	2	
																			0.00	0.01	0.01	1
																				0.00	0.00	0

Price Outcome Lattice

PROBABILITY LATTICE																						
Stage/Year																						
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Step	
1.00	0.57	0.32	0.18	0.10	0.06	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20	
	0.43	0.49	0.42	0.31	0.22	0.15	0.10	0.06	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19	
		0.19	0.32	0.36	0.34	0.29	0.23	0.17	0.13	0.09	0.06	0.04	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	18	
			0.08	0.18	0.26	0.30	0.29	0.27	0.23	0.18	0.14	0.11	0.08	0.06	0.04	0.03	0.02	0.01	0.01	0.01	17	
				0.04	0.10	0.17	0.23	0.25	0.26	0.24	0.22	0.19	0.15	0.12	0.09	0.07	0.05	0.04	0.03	0.02	16	
					0.02	0.05	0.10	0.16	0.20	0.23	0.23	0.23	0.21	0.18	0.16	0.13	0.10	0.08	0.06	0.05	15	
						0.01	0.03	0.06	0.10	0.14	0.18	0.20	0.21	0.21	0.20	0.18	0.16	0.13	0.11	0.09	14	
							0.00	0.01	0.03	0.06	0.10	0.13	0.16	0.19	0.20	0.20	0.19	0.18	0.16	0.14	13	
								0.00	0.01	0.02	0.04	0.06	0.09	0.12	0.15	0.17	0.18	0.19	0.18	0.17	12	
									0.00	0.01	0.02	0.04	0.06	0.09	0.12	0.14	0.16	0.17	0.18	0.18	11	
										0.00	0.01	0.02	0.04	0.06	0.09	0.11	0.13	0.13	0.15	0.15	10	
											0.00	0.00	0.01	0.01	0.03	0.04	0.06	0.08	0.10	0.10	9	
												0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.06	0.08	8	
													0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	7	
														0.00	0.00	0.00	0.00	0.01	0.01	0.01	6	
															0.00	0.00	0.00	0.00	0.00	0.00	5	
																0.00	0.00	0.00	0.00	0.00	4	
																	0.00	0.00	0.00	0.00	3	
																		0.00	0.00	0.00	2	
																			0.00	0.00	0.00	1
																				0.00	0.00	0
Sum of P=	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		

Probability Lattice

## Evolution of Price Distribution in Lattice





# Valuation of Put Option

EXERCISE SHUTDOWN OPTION? - YES VS. NO																					
(Dynamic Programming Approach - Check Next Year)																					
Stage/Year																					
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Step
NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	-	20
	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	-	19
		NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	-	18
			NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	-	17
				NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	-	16
					NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	-	15
						NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	-	14
							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	-	13
								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	-	12
									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	-	11
										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	-	10
											NO	NO	NO	NO	NO	NO	NO	NO	NO	-	9
												NO	NO	NO	NO	NO	NO	NO	NO	-	8
													NO	NO	NO	NO	NO	NO	NO	-	7
														NO	NO	NO	NO	NO	NO	-	6
															NO	NO	NO	NO	NO	-	5
																NO	NO	NO	NO	-	4
																	NO	NO	NO	-	3
																		NO	NO	-	2
																			NO	-	1
																				-	0

<b>ENPV (Flex)</b>	<b>\$ 211,429.64</b>
<b>ENPV (No Flex)</b>	<b>\$ 9,670.73</b>
<b>Option Value</b>	<b>\$ 201,758.92</b>

Put option should be exercised when price of natural gas inputs rises to levels as identified by stage & step in the table above (correlate with actual prices on previous slide)



# Conclusions

- Two system concepts – one fixed and one flexible – were identified to provide IWPP's targeted electricity generation capacity
- Decision analysis used to explore demand uncertainty → flexible system concept optimal
- Binomial lattice used to develop model of fuel price uncertainty and value a put option on the fixed system concept → option had positive value
- Generally, exercises demonstrated the value (to the IWPP investors) of flexibility given uncertainty in demand and fuel prices
- Flexibility allows taking advantage of upside potential (adding additional solar power plant) and/or avoiding significant losses (put option on large natural gas plant)