POWER PLANT DEVELOPMENT OPTIONS

IN ABU DHABI

ESD.71 APPLICATION PORTFOLIO

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Executive Summary

Abu Dhabi has undergone considerable economic growth over the past decade, and high levels of growth are expected to continue over the next fifteen to twenty years. As the economy grows, demand for electricity also will increase. To meet this demand, the Abu Dhabi government has embarked on a program of privatization in the power generation sector, creating opportunities for foreign investors to enter the power generation market in Abu Dhabi as independent power and water producers (IWPPs).

This report evaluates investment options for a potential IWPP, focusing only on the power generation side of the business. The IWPP system concepts analyzed in this report include the potential to build both natural gas-fired and/or solar power plants.

The optimal choice of systems depends on a number of factors (identified in Chapters 1 and 2), including the price of natural gas and the actual evolution of demand for electricity generating capacity, both of which are quantitatively characterized and investigated in this report.

The primary system design parameter is plant size/capacity, based on the IWPP targeting a specific market share of the projected national demand for generation capacity. Two system concepts are defined and used in this report. They are:

- A fixed alternative (System Concept 1) entailing construction and operation of a single, 3000-MW natural gas-fired facility to provide the targeted capacity over the full, 20-year analysis period.
- A phased alternative (System Concept 2) to initially construct and operate two, 1000-MW natural gas power plants and a single, 500-MW solar power plant with the option to add an additional 500-MW solar power plant after the first 10 years.

In Chapter 4, a decision tree is used to explore the effects of demand uncertainty (using high and low deviations from the baseline projection). Based on this analysis, the optimal action at the start of the project is to invest in the phased (flexible) system concept, which has an expected net present value of $624 million over twenty years.

A second analysis, summarized in Chapter 5, uses a lattice model to evaluate the value of a put option on the natural gas-fired plant in the fixed alternative using uncertainty in natural gas prices; demand uncertainty is not considered in this section, and the projected demand growth is approximated with an exponential function. Using a binomial lattice model, the value of this option was found to be $201,759. Thus, in System Concept 1, the IWPP should consider spending up to approximately $200,000 to maintain the ability to close the plant if natural gas prices rise above an acceptable level.

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Chapter 1: Introduction

The oil-rich emirate Abu Dhabi, one of the seven political entities comprising the United Arab Emirates, has experienced rapid economic growth over the past decade. This growth is expected to continue in the coming years and will drive demand for more investment in water and power supply projects in Abu Dhabi. In fact, the 2007 electricity demand forecast published by the Abu Dhabi Water and Electricity Company (ADWEC) identifies over $170 billion in residential and mixed-use development projects announced since 2005, a span of just two years.[1] All of these projects are expected to draw power from the national grid, creating a need to expand capacity significantly in the coming years. Figure 1 shows ADWEC's current projections of electricity demand and installed generation capacity through 2020.

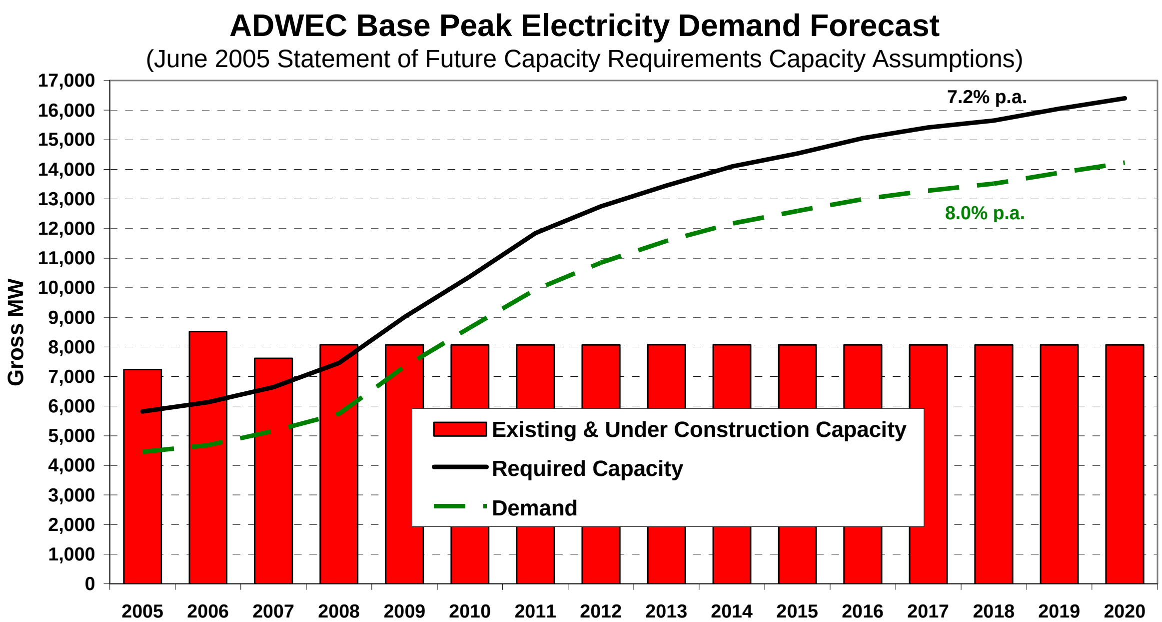

Figure 1: ADWEC Electricity Demand and Capacity Forecasts through 2020
Source: http://www.adwec.ae/forecast

In order to meet this capacity expansion requirement, Abu Dhabi has embarked on a long-term program to privatize the water and power sectors. Five independent power producers (IPPs) or independent water and power producers (IWPPs) already operate in the country on a build-operate-own (BOO) contract basis. All IPPs/IWPPs sell their product to ADWEC, which is the single buyer in the sector and is also responsible for buying fuel to supply the generation plants.[2]

Natural gas power plants currently supply the vast majority of electricity to Abu Dhabi and are expected to continue in this dominant role as Abu Dhabi seeks to reconcile economic

[1] "ADWEC Electricity Demand Forecast 2007-2020." Abu Dhabi Water and Electricity Company. PowerPoint Presentation. Available online: http://www.adwec.ae/forecast/. Accessed 18 September 2007.
[2] "Abu Dhabi Water and Electricity Authority." ABQ Zawya Ltd. 2007. Available online: http://www.zawya.com/cm/profile.cfm/cid1000129. Accessed 18 September 2007.

development with growing concerns about climate change.[3] However, uncertainty regarding the price of natural gas makes sole reliance on this fuel a risky strategy. Solar power generation is another option, one that has already gained some supporters in Abu Dhabi. As part of an ambitious, planned sustainable development called the Masdar City, the Abu Dhabi government is backing construction of a $350 million, 500-MW solar power plant.[4] With political support for the technology and a pilot project already underway, investing in solar power may be an attractive alternative to investing in expanded natural gas electricity generation for an IWPP entering the market in Abu Dhabi.

The System & Its Principal Variables

This analysis is limited to consideration of only two power generation options: natural gas and solar power plants. Also, despite plans to integrate the UAE power grid and – eventually – to create an interconnected electricity grid serving all six members of the Gulf Cooperation Council (GCC)[5], this analysis uses only domestic Abu Dhabi supply and demand forecasts and prices. Recognizing that investments in this market are likely to be undertaken by foreign investor-backed IWPPs building a single plant (or at most a few plants), the analysis is undertaken from the perspective of an IWPP planning to install a set, target electricity generating capacity (in MW).

This capacity can be achieved through construction of a single large plant or a series of smaller plants, and the designer can choose between solar and natural gas powered plants. Thus, the principal variables that the system designer must consider are the size of the power plant(s) constructed initially (and in later phases) and the choice or mix of natural gas and solar power.

Benefits of the System

A reliable, economical supply of electric power is necessary for continued economic development in Abu Dhabi. The IWPP development considered in this analysis will contribute to this supply and thus to Abu Dhabi's economic growth. From the perspective of the system's customers or users, the power supplied must be reliable and economical, as well as abundant. The capacity of the system is a design parameter; the price of power is influenced by construction costs and, in the case of a natural gas power plant, fuel costs, both of which will be modeled in the analysis.

Concerns about Abu Dhabi's high levels of greenhouse gas emissions have begun to affect investment decisions and development policy in the emirate, and the use of natural gas or solar power plants could yield environmental benefits as well cheap, reliable power. Abu Dhabi is a party to the Kyoto Protocol but is not required to reduce its carbon emissions under the agreement[6], and currently there is no carbon emissions pricing or trading scheme in place or

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[3] "Fuel Charts 2006: Annual Fuel Consumption by Fuel." ADWEC. Available online: http://www.adwec.ae/statistics/pdf/98-06/Fuel_Charts2006.PDF. Accessed 18 September 2007.

[4] "Abu Dhabi to Build $350m Solar Power Plant." Reuters. 18 February 2007. Available online: http://www.wfes08.com/page.cfm/T=m/Action=Press/PressID=1. Accessed 17 September 2007.

[5] "Abu Dhabi Water and Electricity Authority." ABQ Zawya Ltd. 2007. Available online: http://www.zawya.com/cm/profile.cfm/cid1000129. Accessed 18 September 2007.

[6] "State of the Environment Abu Dhabi – Themes - Atmosphere." Environment Agency – Abu Dhabi. 2007. Available online: http://www.soe.ae/Abu_Themespage.aspx?m=43. Accessed 17 September 2007.

planned for the country. Consequently, no attempt is made to quantify and analyze the environmental benefits of the generation options.

Contextual Factors – Uncertainties

The environment in which the IWPP will operate greatly influences the value of the project. Factors shaping this environment include:

- *Fuel prices.* The market price of natural gas directly influences the cost of power produced by the natural gas powered plant option and thus affects both the absolute value of that option and its value relative to the solar power plant option, which operates independently of natural gas prices. Price of the fuel could be altered by discovery and development of new reserves, improved recovery technology, natural disasters, or geopolitical events like wars or terrorist attacks that may constrain or interrupt supply.
- *Technical change.* The solar power industry presently is undergoing rapid growth and technological change, and further breakthroughs in technologies could reduce the costs of building a solar power plant. Likewise, technological developments in natural gas power plants could alter the cost structure and performance of that type of plant. Furthermore, technological changes in other generation technologies could undercut either or both of the subject technologies, but for the purposes of this analysis any such changes would be considered external to the system.
- *Privatization and regulation.* Abu Dhabi currently supports private investment in power generation (through IWPPs) as a means to meet projected demand. However, changes in this policy, including the potential for re-nationalization of electricity generation infrastructure, could significantly impact the system under consideration. Furthermore, growing concern about climate change could lead to increased environmental regulation of the power generation sector in Abu Dhabi.
- *Changes in the industrial structure/market.* Abu Dhabi's plans to construct interconnections with the rest of the UAE and eventually with other GCC countries would drastically expand and alter the market for power produced by the IWPP.
- *Economic/financial policy and capital flow controls.* Private IWPP development in Abu Dhabi relies on participation of foreign investors, a characteristic made possible by relatively open global capital markets. Changes in the control of private capital flows into and out of Abu Dhabi would thus affect the value and viability of the IWPP system.

Chapter 2: Defining the Uncertainties

As noted in the previous chapter, an IWPP investing in the Abu Dhabi power market faces a number of uncertainties including:

- 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, and
- end-user demand for electric power.

The ways in which each of these categories of uncertainty is resolved over time define the operating environment for the IWPP and significantly affect the value of an investment. The analyses that follow in this report focus on the two sources of uncertainty – fuel prices and demand for electric power – that can most readily be quantitatively characterized and analyzed using net present value, decision tree, and lattice valuation methods.

Natural Gas Prices

Abu Dhabi produces natural gas and exports modest amounts of it, but the emirate is also an importer of gas for domestic consumption and is expected to increase import volumes in the coming years. The Dolphin Project, which came online during the second half of 2007, supplies natural gas from Qatar to Abu Dhabi, Dubai, and Oman.[7] In Abu Dhabi, electric power generators all purchase fuel from the Abu Dhabi Water and Electricity Authority, and available sources indicate that the purchases are made on the basis of economic costs.[8]

The market price of natural gas directly influences the cost of power produced by the natural gas powered plant option and thus affects both the absolute value of that option and its value relative to the solar power plant option, which operates independently of natural gas prices. Price of the fuel could be altered by discovery and development of new reserves, improved recovery technology, or geopolitical events like wars or terrorist attacks that may constrain or interrupt supply.

Gas prices are an important part of this analysis, but historical price data for Abu Dhabi or the Arab Gulf region are not available at this time. To complete the analysis, publicly available natural gas price data from the United States is used instead to provide quantifiable data on the variation in natural gas prices over time. Figure 2 shows the five-year history of both well-head and electric power generator natural gas prices in the United States. Close correlation between the two prices can be observed over this period; due to unavailability of electric power price data over a longer period, the wellhead prices over a thirty-two-year period are presented in Figure 3.[9]

[7] "United Arab Emirates Energy Data, Statistics, and Analysis." U.S. Department of Energy, Energy Information Administration, 2007. Available online: http://www.eia.doe.gov/emeu/cabs/UAE/NaturalGas.html. Accessed 5 October 2007.
[8] "Abu Dhabi Water and Electricity Authority." ABQ Zawya Ltd. 2007. Available online: http://www.zawya.com/cm/profile.cfm/cid1000129. Accessed 18 September 2007.
[9] In Figure 3, the x-axis has been altered to show sequentially numbered periods rather than the actual date. This change was made to enable Excel to properly calculate the exponential growth trendline displayed on the figure.

A trendline approximates the price growth over this period using an exponential growth function, and price volatility will be calculated directly from the data using a regression technique.

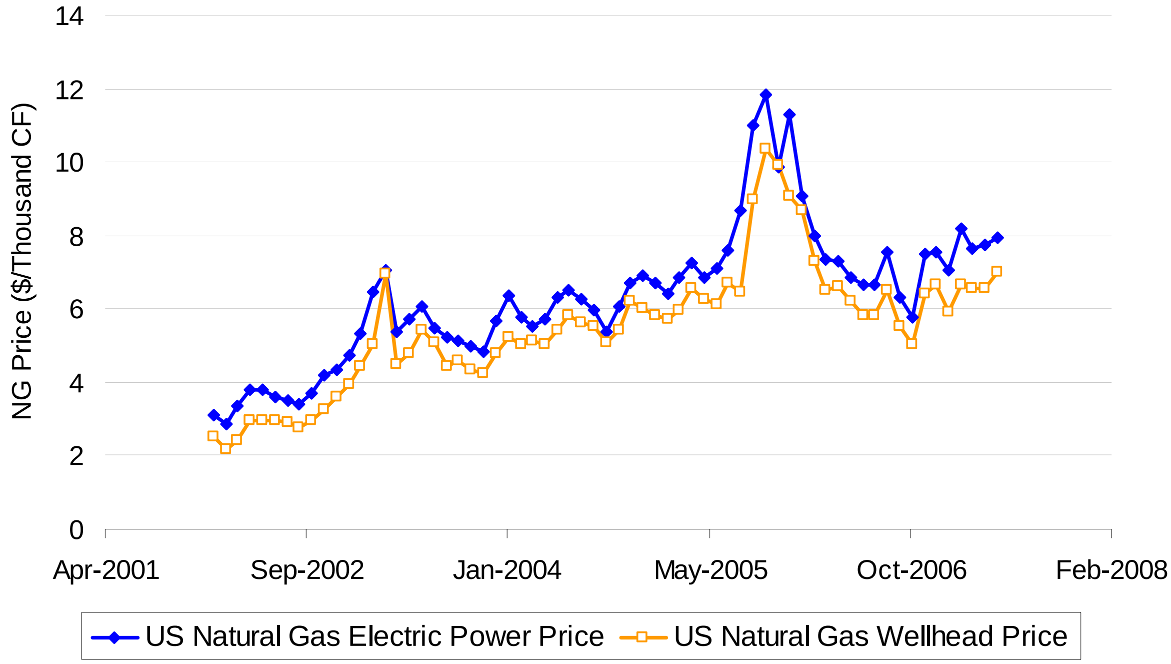

Figure 2: 5-Yr U.S. Natural Gas Wellhead and Electric Power Prices
(Source: http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm)

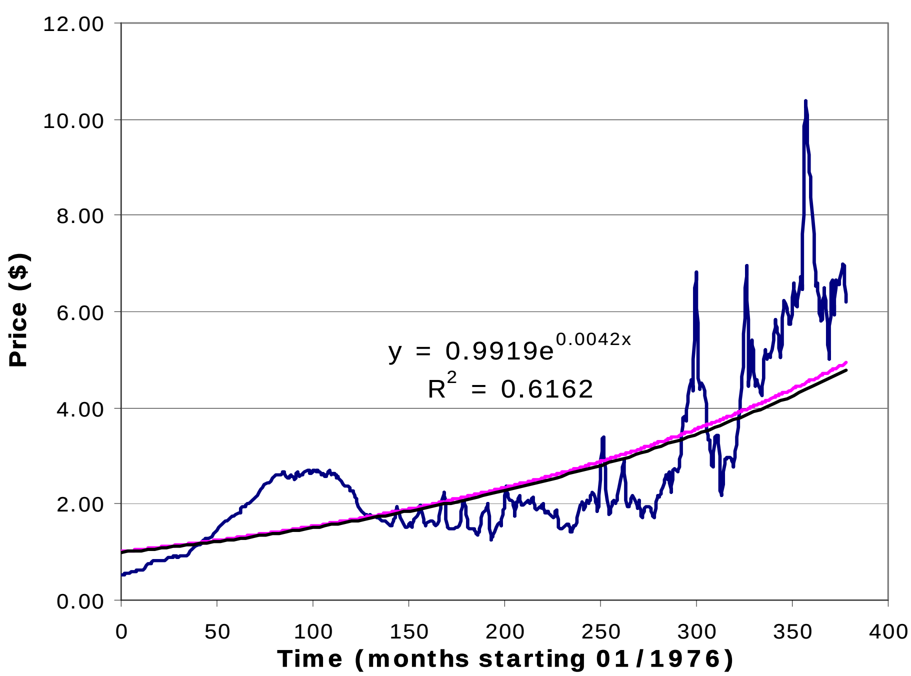

Figure 3: 32-Year Natural Gas Wellhead Price History
(Source: http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm)

Electric Power Demand in Abu Dhabi

The demand for electric power in Abu Dhabi is determined by a wide range of interrelated factors (e.g., economic health, geopolitical developments, government energy policies, etc.) which are characterized by uncertainty. Figure 4 shows the annual peak and minimum demands in Abu Dhabi over a sixteen-year period from 1990 through 2006 as reported by the Abu Dhabi Water and Electricity Company. Figure 5 shows the high, medium, and low peak demand forecasts through 2020 developed and published by the same company. Taken together, these figures show that electricity demand growth in Abu Dhabi has been sustained since at least 1990 but that ADWEC expects the growth rate to slow somewhat over the period between 2006 and 2020, with an inflection point in 2008 or 2009. The ADWEC forecast acknowledges uncertainty by using high and low forecasts around the base forecast; the analysis presented in this report uses a distribution around a base forecast to characterize the uncertainty in demand for power produced by the IWPP.

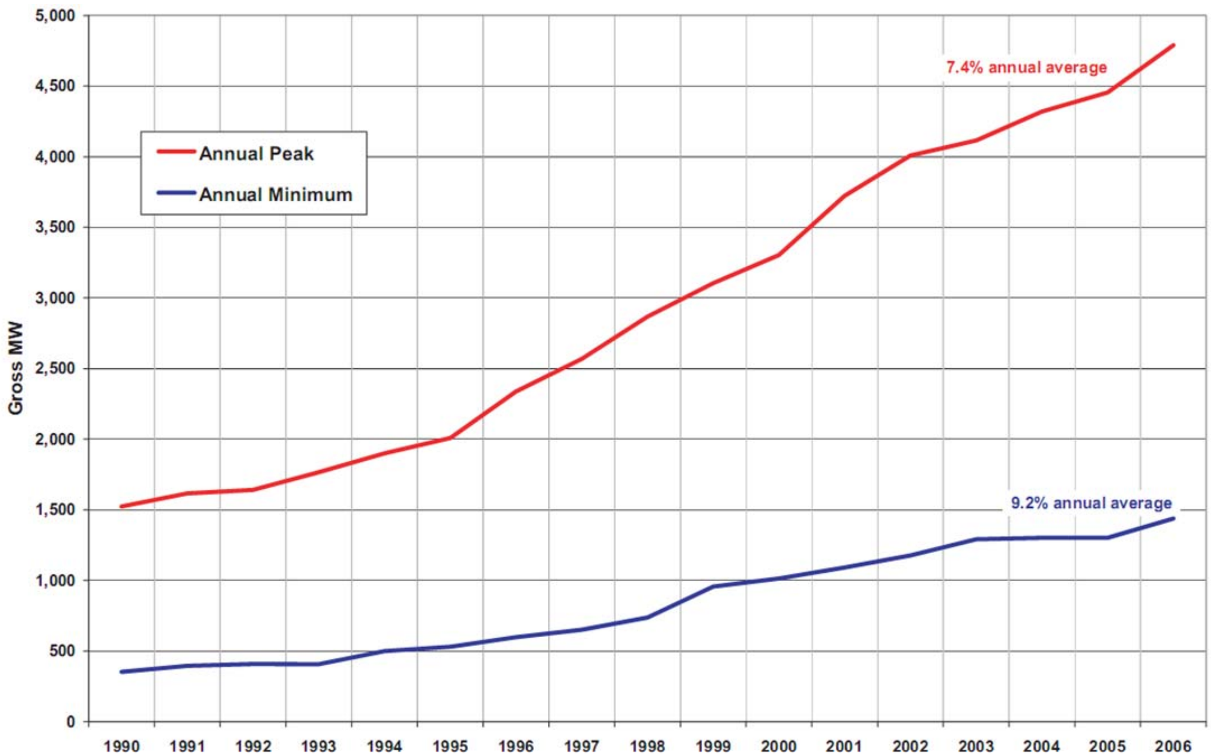

Figure 4: Abu Dhabi Electric System Peak & Minimum Demand 1990-2006
(Source: ADWEC Statistical Report, http://www.adwec.ae/statistics/)

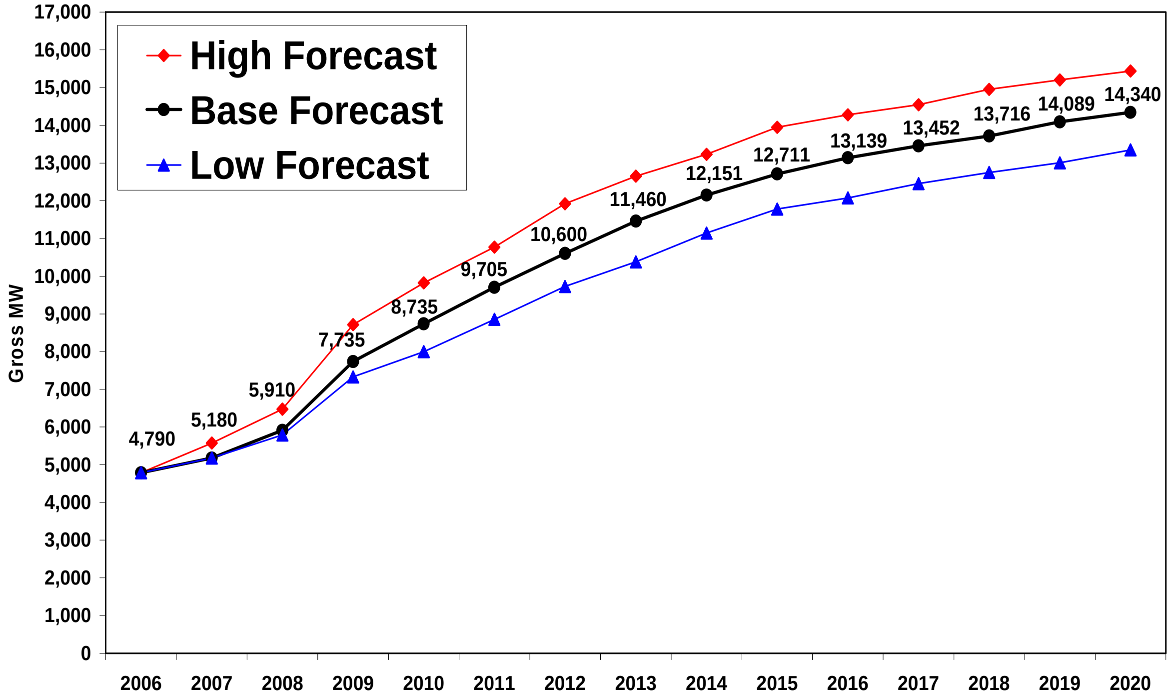

Figure 5: Abu Dhabi Peak Demand Forecast to 2020
(Source: ADWEC Electricity Demand Forecast 2006-2020, http://www.adwec.ae/forecast)

Chapter 3: Defining the Major System Concepts

This chapter defines two system development concepts available to the IWPP entering the Abu Dhabi market. These concepts are then used in the decision analysis presented in Chapter 4. The performance, measured by NPV, of these two system concepts is analyzed for a twenty-year time frame beginning in 2008. The IWPP investors target a market share of twenty percent of the generation capacity in Abu Dhabi, or about 3350 gross MWe by 2027.[10] (This amounts to about one third of the total anticipated demand for new domestic electricity generating capacity during this two-decade period.)

In order to meet the market share target, the IWPP board must choose between one of the following two investment options:

System Concept 1 – Fixed Option

The fixed-capacity option entails construction and operation of a single, natural gas-fired facility to serve the demand over the full, 20-year analysis period. This proposed facility has a capacity of 3000 MW, some 300 MW below the forecast 2027 peak capacity demand. (This planned short-fall can be interpreted as a conservative strategy in the face of considerable uncertainty on the 20-year investment horizon.) The initial capital investment needed for this facility is $1500 million, and a salvage value of zero is assumed. Table 1 shows the key years in the system model.

Table 1: System Concept 1 - Fixed Option

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				

[10] It is important here to note that the spreadsheet model used to calculate NPV was generated for the sole purpose of completing this exercise and should not be used for any other purpose. An attentive reader is sure to note that the definition of production targets in terms of plant capacity (MW) is not dimensionally consistent with incorporating fuel prices and other variable costs of generating electricity, which must incorporate time, as in kilowatt-hours. The dimensionality is accounted for within the model's calculations but is not readily apparent in the tables presented herein.

System Concept 2 – Phased Mixture of Natural Gas and Solar

The flexible option entails initial construction and operation of two smaller natural gas-fired power plants (1000 MW each) and a single, 500-MW solar power plant. After ten years, the IWPP board may choose to add a second 500 MW solar plant to augment the initial capacity, thus equaling the total generating capacity of the first system concept at the twenty-year mark. Capital expenditures are $500 million for a 1000 MW natural gas power plant and $350 million for a 500 MW solar power plant.[11] Again, salvage values are assumed to be zero. Table 2 shows key expenditures and other parameters as they appear in the system model spreadsheet.

Table 2: System Concept 2 - Phased Development

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				

[11] The power plant capital cost is derived from the announced (pre-construction budget) cost of a 500-MW solar power facility being built in Abu Dhabi as part of the Masdar Initiative.

Chapter 4: Decision Analysis

This chapter presents a decision analysis based on the two system concepts described in Chapter 3. Two decision stages are assumed, and the second stage occurs ten years after the first. The performance of the systems is measured by NPV, and the uncertainty examined using this decision analysis is the future demand for electric power generation capacity in Abu Dhabi.

Options and Uncertainties

At decision stage 1 (year 0), the IWPP investors must decide whether to invest in a single large plant (fixed option, Option A) or a flexible option allowing them to adapt to the actual progression of demand over the first half of the analysis period (Option B). If the decision is to invest in Option A initially, the investors must at decision stage 2 determine whether to continue operating the large plant or close operations (because of lower-than-expected demand). If the initial decision is to invest initially in Option B, at decision stage 2, the investors must decide between continuing to operate just the initial plant (built at stage 1), building additional capacity to respond to further demand growth, or even shutting down production.

The structure of the decision analysis tree is shown in Figure 6. The first decision is to be taken at year 0, and the initial plant would thus subsequently come online at year 1. The second-stage decision is to be taken in year 10, with any changes in capacity or production taking place in year 11. With each decision stage, there is associated uncertainty about future power demand in Abu Dhabi. The baseline demand forecast is included as "med." (e.g., medium), while high and low forecast variations of +/- 20% are shown at each stage as well. Each demand forecast is associated with a probability; at the first stage, these probabilities reflect 50% confidence in the baseline forecast and equal chances that reality will exceed or lag that forecast. (Thus, the baseline forecast is assumed to be risk-neutral rather than optimistic or conservative.) At the second decision stage, the estimated probabilities are redistributed to reflect an assumption that high or low economic growth in the first period forebears similar demand in the second, a not unreasonable assumption for the potential investors to make in the absence of particular knowledge of factors (planned government policy shifts, etc.) likely to change the economic outlook for Abu Dhabi between the two periods. Similarly, absent unpredictable events outside the scope of forecast used in this analysis, the demand is unlikely to shift drastically from high to low or low to high; this too is reflected in the second stage probabilities.

For Option B, two production choices are shown at decision stage 2 (in addition to the option to shut down production). First, the existing three plants can be operated for the full period without exercising the option to build an additional solar power plant. This is denoted P-SQ for "produce – status quo" on the figure. Second, the option to build an additional solar power plant can be exercised; this is denoted P - +1S for "produce – add one solar."

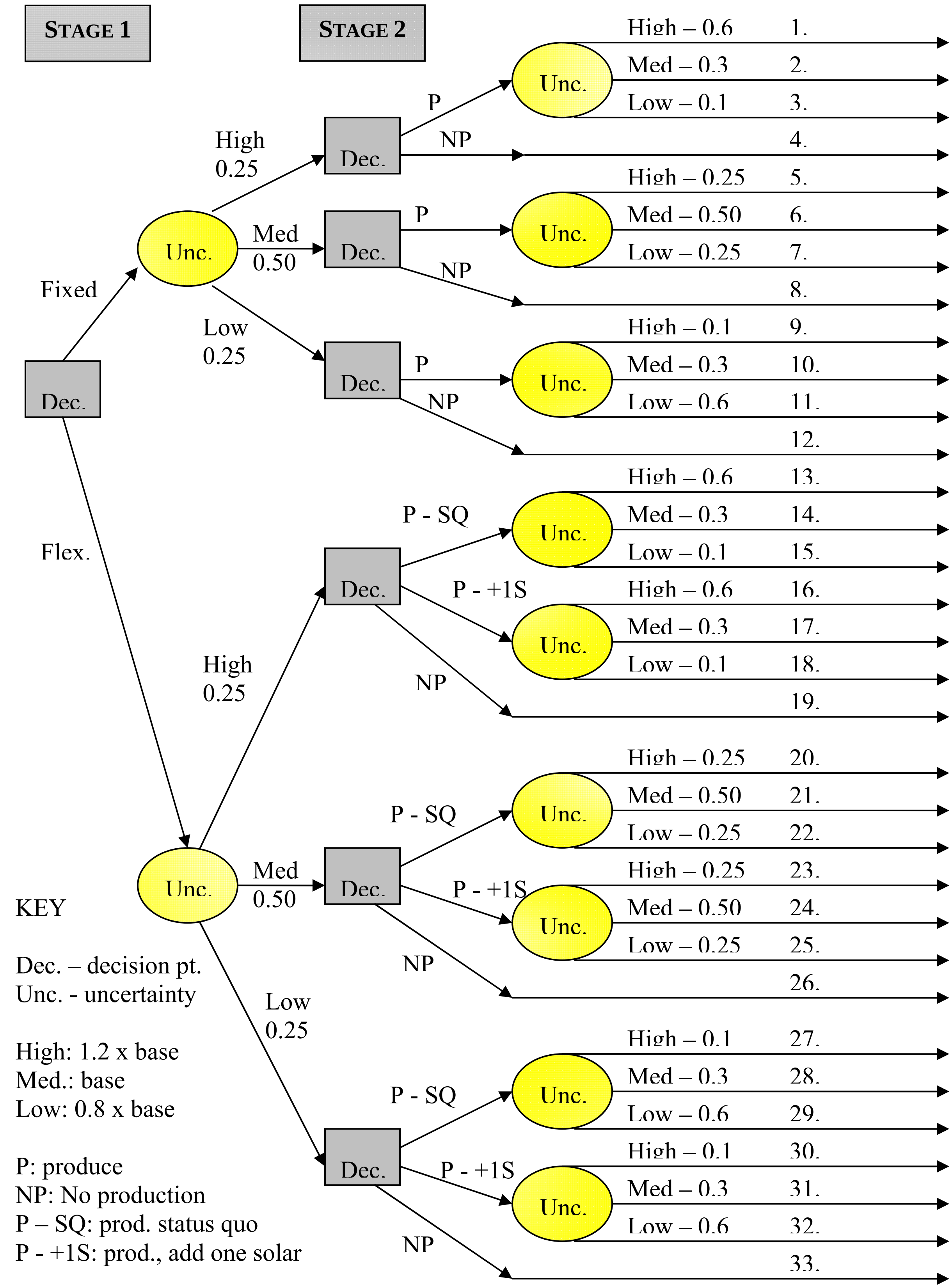

Figure 6: Decision Analysis Tree

Two-Stage Decision Analysis

Figure 8 shows the decision tree with numerical results and expected values calculated. The far right column of figures shows the expected value for each of the 33 possible states; these values were calculated using the system model spreadsheet described in Chapter 3.

The determination of expected values for each of the system concepts then proceeded by working through the decision tree from right to left, toward the initial decision in Year 0. The values at points of uncertainty are probability-weighted sums of the expected values of outcomes associated with each point of uncertainty. The values at decision stage 2 are equal to the expected value of the best option available at that stage. (Note that the option to stop production at the beginning of stage 2 was not optimal in any case and that the value at the stage 2 decision points – not explicitly entered in the decision tree – is simply equal to the highest of the expected values achievable from that point.) The value at the uncertainty points in stage 1 were, in turn, calculated as the probability-weighted expected values of each of the possible (high, medium, low) demand evolution possibilities.

Optimal Decisions from Decision Tree

The optimal decisions at each stage, as determined from the decision analysis tree and denoted in Figure 8 using bolded arrows from the decision points, are as follows:

- Stage 1: The optimal decision is to invest in the flexible system concept (Option B). This has an expected value of $624 million, easily superior to the fixed case, which loses value.
- Stage 2: Regardless of the demand level observed for the first ten years, the subsequent optimal action at decision stage 2 is to exercise the option for an additional solar power plant.

Value at Risk and Gain

The value at risk and gain (VARG) curves associated with the expected values of the decision nodes at stage 2 in the tree are shown below in Figure 7. These curves clearly show the dominance of the phased system concept, which is far to the right relative to the fixed plant.

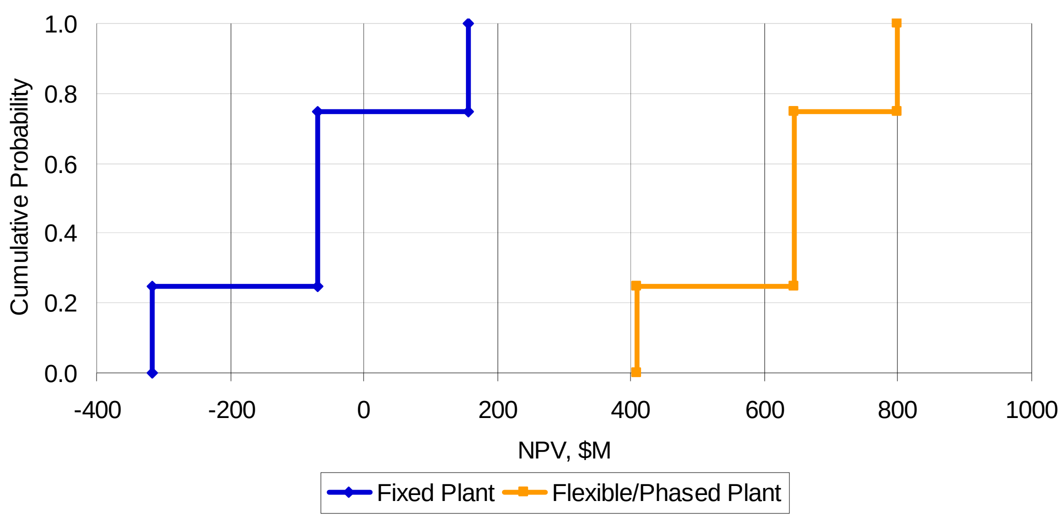

Figure 7: VARG Curves, Values at Stage 2

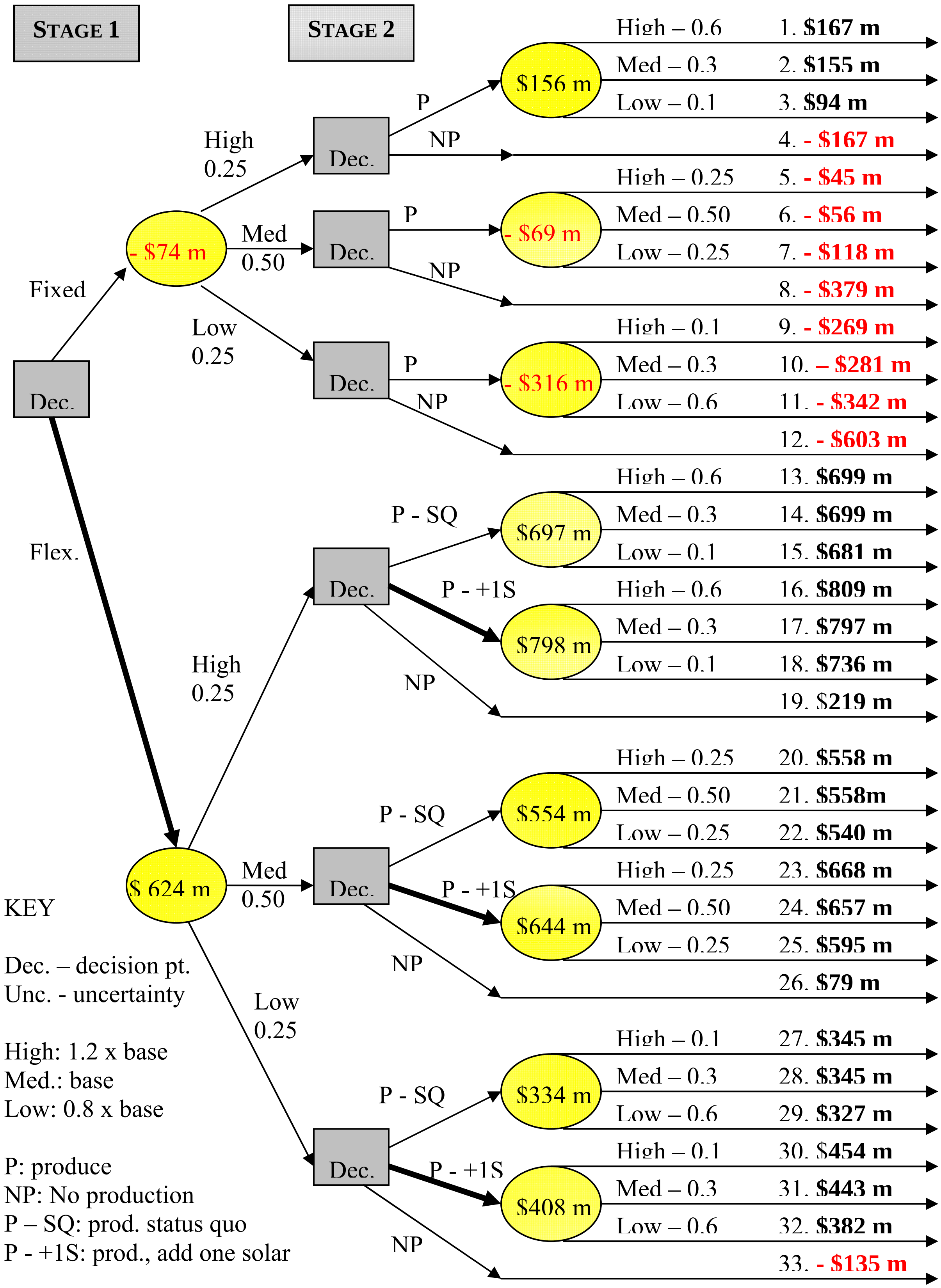

Figure 8: Decision Tree with Expected Values

Chapter 5: Lattice Analysis

This chapter complements the previous analysis by using a binomial lattice of price development and a simple dynamic programming approach to value the project. Specifically, the value of a put option to abandon the large natural gas-fired power plant from System Concept 1 (Fixed) is calculated. The following section presents historical natural gas price data and describes the lattice parameters obtained from this historical data.

Natural Gas Price – Historical Data

The well-head prices of natural gas in the United States for a period beginning in January 1976 and ending in July 2007 was used to obtain historical trends for this analysis; the data are presented in Chapter 2, Figure 3. (As explained in a prior section, this U.S. data is used as a proxy for Abu Dhabi price data, which is not available at this time.)

The black trendline shown on the graph in Figure 3 approximates the progression of the natural gas price over the period of interest. The trendline equation, which is taken as the forecast trend for this analysis, identifies the rate of growth as 0.42% (0.0042) per period – in this case per month – or 5.04% per year. The actual price of natural gas in July 2007 was $6.19 per thousand cubic feet. This value is taken as the initial price of the gas (S) in the lattice analysis. The volatility of the historical price is 38.13% and was obtained by performing a regression on the price data shown in Figure 3.[12]

Given these input data values and a time period of one year ($\Delta t = 1$), the u, d, and p lattice parameters were calculated by using the following formulas:

$$u = e \exp(\sigma \sqrt{\Delta t}) \qquad d = e \exp(-\sigma \sqrt{\Delta t}) \qquad p = 0.5 + 0.5\,(v/\sigma)\sqrt{\Delta t}$$

The calculated values were: u = 1.46419, d = 0.68297, and p = 0.56609. The price outcomes lattice and associated probabilities lattice are included below as Table 3 and Table 4 .

Table 3: Price Outcome Lattice

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	1
																				0.00	0

[12] No volatility adjustments were made to the data. Although it might be reasonable to assume that geopolitical instability in the Middle East might increase the volatility of prices there, this effect is assumed to be roughly counteracted by the close economic ties between the Abu Dhabi government and its primary natural gas suppliers, which are small neighboring states.

Table 4: Probability 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	0.00	0.01	0.02	0.04	0.06	0.09	0.12	0.14	0.16	0.17	0.18	11
										0.00	0.00	0.01	0.01	0.02	0.04	0.06	0.09	0.11	0.13	0.15	10
											0.00	0.00	0.00	0.01	0.01	0.03	0.04	0.06	0.08	0.10	9
												0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.06	8
													0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	7
														0.00	0.00	0.00	0.00	0.00	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	1
																				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	1.00	

Valuation of Put Option to Close Plant

The price and probabilities lattices were used in conjunction with the previously developed system model to value a put option on the single, large natural gas plant in System Concept 1. This value is shown in Table 5 below. This analysis does not include the capital cost of the plant, which would be the same with and without the option and would in both cases be regarded as a sunk cost with no effect on the decision to exercise the option.

As a first step, the price lattice, system model, and probability lattice were used as inputs to generate the probability-weighted net benefits lattice included as Table 6. As shown in Table 7, the probability-weighted net benefits were summed for each year and converted into an expected value of the project with no put option. This value was $9670.73. Table 8 shows the calculation of this value within the lattice and is simply an alternative presentation of the data contained in the previous two tables.

Next, the expected net present value with a shutdown (put) option on the project was calculated using a simple dynamic programming method. The corresponding lattice, included as Table 9, shows that the expected net present value in this case is $211,429.64. Table 10 is a decision aid tool that shows at what times and under what circumstances (in terms of price evolution as indicated by the step) it is optimal to exercise the put option.

The table below shows that the value of the put option is $201,758.92, which is the difference between the expected net present value with the option and the expected net present value of the project without the added flexibility of the option.

Table 5: Option Value

ENPV (Flex)	$ 211,429.64
ENPV (No Flex)	$ 9,670.73
Option Value	$ 201,758.92

Table 6: Probability-Weighted Net Benefits

PROBABILITY-WEIGHTED NET BENEFITS (PROFITS) 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
0.00	6882.61	2968.46	148.25	-1621.32	-2582.18	-2987.79	-3043.05	-2895.38	-2643.48	-2349.77	-2051.51	-1769.43	-1513.74	-1288.29	-1093.19	-912.96	-758.89	-630.27	-523.12	-434.01	20
	7842.91	9764.70	7865.34	4344.98	649.93	-2489.33	-4819.70	-6349.67	-7204.00	-7540.32	-7507.93	-7231.24	-6806.34	-6303.48	-5771.66	-5166.46	-4578.23	-4035.22	-3540.95	-3095.80	19
		4674.45	8719.10	9991.88	8537.67	5286.99	1260.53	-2762.82	-6309.93	-9162.02	-11273.70	-12700.42	-13545.51	-13926.49	-13955.96	-13530.86	-12884.16	-12126.64	-11306.29	-10459.00	18
			2548.37	6296.77	9240.47	10197.77	8965.78	5970.03	1877.19	-2665.16	-7152.64	-11253.92	-14790.94	-17700.95	-19997.69	-21420.33	-22224.33	-22565.21	-22525.17	-22178.35	17
				1313.07	4023.45	7148.12	9502.16	10281.11	9217.49	6474.91	2457.88	-2357.70	-7535.55	-12732.94	-17713.80	-22010.54	-25642.01	-28648.82	-31043.47	-32858.46	16
					651.27	2375.49	4934.23	7609.01	9589.17	10267.53	9356.46	6862.81	2994.34	-1944.13	-7633.34	-13589.27	-19513.91	-25233.97	-30605.08	-35527.99	15
						314.43	1327.94	3149.39	5501.69	7843.14	9574.03	10205.89	9444.04	7190.63	3499.66	-1462.86	-7326.96	-13824.05	-20716.79	-27797.41	14
							148.84	713.55	1899.50	3697.79	5855.31	7952.24	9521.35	10150.59	9540.45	7404.83	3865.59	-951.91	-6900.81	-13807.95	13
								69.43	372.23	1098.08	2353.73	4088.28	6085.67	8012.86	9490.74	10008.07	9375.62	7458.89	4180.75	-462.67	12
									32.03	189.84	614.45	1437.03	2713.07	4381.80	6263.75	7970.22	9214.36	9714.24	9210.83	7505.52	11
										14.65	95.13	335.20	849.22	1730.68	3010.64	4564.60	6230.32	7783.15	8953.00	9466.15	10
											6.66	47.02	179.22	489.07	1070.06	1964.63	3170.97	4620.06	6168.50	7616.12	9
												3.01	23.00	94.31	275.92	635.83	1238.88	2124.42	3284.11	4651.83	8
													1.36	11.15	49.01	150.88	368.48	761.24	1380.87	2254.42	7
														0.61	5.38	24.85	81.03	209.63	457.51	874.77	6
															0.28	2.54	12.45	42.97	117.36	269.74	5
																0.12	1.19	6.18	22.53	64.78	4
																	0.05	0.56	3.05	11.70	3
																		0.02	0.26	1.50	2
																			0.01	0.12	1
																				0.00	0

Table 7: Calculation of Expected NPV (No Option)

	CALCULATION OF EXPECTED NET PRESENT VALUE																				
	Stage/Year																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
E[Benefits]	0.00	14725.52	17407.61	19281.05	20325.39	20520.60	19845.68	18276.74	15784.65	12331.89	7868.67	2327.87	-4381.22	-12380.83	-21834.57	-32959.75	-45366.70	-59369.55	-75294.72	-93382.92	-113904.98
PV(E[Benefits])	0.00	13509.65	14651.64	14888.51	14399.02	13336.98	11833.33	9998.00	7921.78	5677.95	3323.81	902.13	-1557.68	-4038.36	-6533.92	-9048.70	-11426.50	-13718.71	-15962.01	-18162.01	-20324.17
ENPV - 20 yrs	9670.73																				

Table 8: Expected NPV - No Flexibility/No Option

EXPECTED NET PRESENT VALUE (ENPV) - NO FLEXIBILITY (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
9670.73	(140252.54)	(376367.28)	(712002.68)	(1179561.77)	(1821322.42)	(2691780.86)	(3860131.40)	(5412540.90)	(7453538.58)	(10105262.21)	(13502323.57)	(17778425.99)	(23038174.36)	(29303099.39)	(36413702.80)	(43857590.12)	(50648552.26)	(54808914.93)	(52703652.77)	(38001268.12)	20
	207270.05	108155.94	(39823.55)	(251747.65)	(547305.61)	(951893.19)	(1497773.07)	(2225139.70)	(3182771.99)	(4427686.48)	(6022747.42)	(8030430.24)	(10499678.36)	(13440732.87)	(16779448.55)	(20277134.12)	(23473488.88)	(25446162.86)	(24499894.04)	(17681672.58)	19
		334162.80	273715.80	181033.17	46962.18	(140318.99)	(395846.13)	(738369.80)	(1190664.06)	(1779369.50)	(2533883.61)	(3483457.41)	(4651070.91)	(6041699.11)	(7621009.95)	(9277981.52)	(10797624.22)	(11749846.27)	(11344192.29)	(8203555.10)	18
			419966.88	382904.68	324159.62	238241.49	118149.98	(44862.89)	(261441.19)	(544056.56)	(906495.86)	(1362512.50)	(1922975.83)	(2590404.47)	(3349037.27)	(4147403.98)	(4884940.86)	(5361171.00)	(5207687.93)	(3782467.55)	17
				477068.07	453458.94	414821.81	357904.53	278624.84	171996.75	32157.73	(147397.46)	(373193.35)	(650450.23)	(980540.93)	(1356366.75)	(1754235.45)	(2126957.45)	(2381160.17)	(2345302.75)	(1720242.10)	16
					513770.88	497188.06	469738.54	429516.36	374174.77	300934.07	206685.56	88276.62	(56878.02)	(229616.75)	(426881.46)	(637937.02)	(840490.37)	(991127.94)	(1010137.25)	(758312.76)	15
						535607.97	521903.74	499900.03	468481.13	426305.36	371848.31	303530.24	219994.97	120653.40	6678.88	(117237.31)	(240415.13)	(342744.52)	(387346.53)	(309618.82)	14
							546236.31	532730.63	512470.53	484785.05	448888.83	403935.74	349142.95	284037.63	208914.01	125644.15	39491.21	(40304.73)	(96844.51)	(100324.61)	13
								548044.54	532989.47	512063.03	484824.53	450770.10	409384.29	360248.55	303247.00	238936.71	170054.10	100768.94	38660.76	(2698.88)	12
									542560.58	524786.90	501586.82	472616.08	437483.99	395797.29	347248.82	291782.26	230955.43	166573.04	101867.48	42838.84	11
										530721.97	509405.62	482806.18	450591.15	412379.07	367773.56	316432.18	259362.99	197267.50	131350.38	64080.00	10
											513052.72	487559.37	456705.02	420113.68	377347.36	327930.18	272613.75	211585.00	145102.74	73987.98	9
												489776.51	459556.84	423721.50	381813.09	333293.45	278794.59	218263.42	151517.56	78609.59	8
													460887.08	425404.38	383896.13	335795.16	281677.66	221378.59	154509.77	80765.34	7
														426189.36	384867.77	336962.09	283022.47	222831.66	155905.49	81770.90	6
															385321.00	337506.40	283649.77	223509.45	156556.52	82239.94	5
																337760.30	283942.37	223825.61	156860.20	82458.73	4
																	284078.85	223973.08	157001.85	82560.78	3
																		224041.87	157067.92	82608.38	2
																			157098.74	82630.59	1
																				82640.95	0

Table 9: Expected NPV with Shutdown (Put) Option

EXPECTED NET PRESENT VALUE (ENPV) - WITH SHUTDOWN OPTION																					
(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
211429.64	174694.91	112928.93	44470.92	(15788.01)	(44418.14)	(90790.24)	(163347.30)	(274551.05)	(442801.35)	(695300.39)	(1072350.94)	(1633846.44)	(2469133.01)	(3712092.49)	(5564356.72)	(8208955.10)	(12053952.10)	(17684372.58)	(25928986.55)	(38001268.12)	20
	303208.57	260969.05	202394.62	130257.33	52057.36	(16447.68)	(48218.10)	(98189.39)	(174923.88)	(291086.98)	(465452.13)	(725928.12)	(1114159.22)	(1692560.72)	(2555147.23)	(3787867.55)	(5580654.08)	(8206255.10)	(12051252.10)	(17681672.58)	19
		375800.59	341584.84	291122.10	224630.76	144900.25	59513.60	(15522.25)	(49971.88)	(102540.79)	(182362.93)	(302427.74)	(482128.89)	(750545.93)	(1151495.23)	(1725642.10)	(2561170.80)	(3785167.55)	(5577954.08)	(8203555.10)	18
			436019.10	409769.78	368916.74	312448.26	240558.96	155974.82	66206.56	(12730.42)	(50315.38)	(104885.11)	(187317.03)	(311141.18)	(496758.84)	(763712.76)	(1152726.57)	(1722942.10)	(2558470.80)	(3782467.55)	17
				482343.02	462553.94	430441.57	384617.25	324103.42	249052.06	162041.25	70321.59	(10407.58)	(49801.43)	(106179.92)	(191355.69)	(315018.82)	(495754.83)	(761012.76)	(1150026.57)	(1720242.10)	16
					515156.22	499657.15	474125.96	437287.34	387890.59	325050.97	248916.70	161896.64	70833.61	(9256.92)	(48899.76)	(105724.61)	(189309.00)	(312318.82)	(493054.83)	(758312.76)	15
						535866.79	522382.26	500783.21	470108.15	429296.56	377335.17	313570.13	238315.77	153983.45	67107.65	(8098.88)	(46366.71)	(103024.61)	(186609.00)	(309618.82)	14
							546262.19	532780.46	512566.47	484969.80	449244.55	404620.68	350461.79	286577.04	213803.62	135059.05	57619.50	(5398.88)	(43666.71)	(100324.61)	13
								548044.54	532989.47	512063.03	484824.53	450770.10	409384.29	360248.55	303247.00	238936.71	170054.10	100768.94	38660.76	(2698.88)	12
									542560.58	524786.90	501586.82	472616.08	437483.99	395797.29	347248.82	291782.26	230955.43	166573.04	101867.48	42838.84	11
										530721.97	509405.62	482806.18	450591.15	412379.07	367773.56	316432.18	259362.99	197267.50	131350.38	64080.00	10
											513052.72	487559.37	456705.02	420113.68	377347.36	327930.18	272613.75	211585.00	145102.74	73987.98	9
												489776.51	459556.84	423721.50	381813.09	333293.45	278794.59	218263.42	151517.56	78609.59	8
													460887.08	425404.38	383896.13	335795.16	281677.66	221378.59	154509.77	80765.34	7
														426189.36	384867.77	336962.09	283022.47	222831.66	155905.49	81770.90	6
															385321.00	337506.40	283649.77	223509.45	156556.52	82239.94	5
																337760.30	283942.37	223825.61	156860.20	82458.73	4
																	284078.85	223973.08	157001.85	82560.78	3
																		224041.87	157067.92	82608.38	2
																			157098.74	82630.59	1
																				82640.95	0

Table 10: Decision to Exercise Shutdown (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	NO	YES	YES	YES	YES	YES	YES	YES	-	16
					NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	-	15
						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	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

Chapter 6: Conclusion

Abu Dhabi has undergone considerable economic growth over the past decade, and high levels of growth – in the economy and in the demand for electricity - are expected to continue over the next fifteen to twenty years. This report has presented and partially evaluated investment options for a potential IWPP, focusing only on the power generation side of the business.

The IWPP system concepts analyzed in this report included the potential to build both natural gas-fired and/or solar power plants. The optimal choice of system concepts depends on a number of factors, including the price of natural gas and the actual evolution of demand for electricity generating capacity, both of which have been quantitatively characterized and investigated.

The primary system design parameter used was plant size/capacity, and the following two system concepts were defined and investigated:

- A fixed alternative (System Concept 1) entailing construction and operation of a single, 3000-MW natural gas-fired facility to provide the targeted capacity over the full, 20-year analysis period.
- A phased alternative (System Concept 2) to initially construct and operate two, 1000-MW natural gas power plants and a single, 500-MW solar power plant with the option to add an additional 500-MW solar power plant after the first 10 years.

A decision tree was used to explore the effects of demand uncertainty (using high and low deviations from the baseline projection). Based on this analysis, the optimal action at the start of the project is to invest in the phased (flexible) system concept, which has an expected net present value of $624 million over twenty years.

A second analysis utilized a lattice model to evaluate the value of a put option on the natural gas-fired plant in the fixed alternative using uncertainty in natural gas prices; demand uncertainty was not considered in this section, and the projected demand growth was approximated with an exponential function. Using a binomial lattice model, the value of this option was found to be $201,759. Thus, in System Concept 1, the IWPP should consider spending up to approximately $200,000 to maintain the ability to close the plant if natural gas prices rise above an acceptable level.

The two analysis exercises included in this report are not sufficient to fully inform the IWPP's investment decision, but they do clearly demonstrate the importance of considering both the effects of uncertainty and the potential value of options on the systems. Careful design and execution of additional modeling and analyses are recommended to provide a robust investment plan accounting for fuel cost and demand evolution uncertainties. Traditional business risk assessment and management methods must still be employed to minimize exposure to discontinuous, non-quantifiable sources of risk like drastic changes in the relevant regulatory regime.

Chapter 7: Course Reflections

This final chapter offers some reflections on the course, Engineering Systems Analysis for Design. Specifically, the following two questions are addressed:

- Where do you see the most use for the flexible approach to design and valuation of options that the course has stressed?
- What do you feel that you have learned from the process of doing the application portfolio?

In response to the first question, the flexible design approach stressed throughout the course has obvious usefulness in basic plant design applications like the one explored in this report. More generally, I would expect flexibility and real options analysis to have wide applicability across capital expansion/capital investment projects. Production plants – for manufacturing, power, water, or a host of other outputs – are precisely the kinds of technological systems to which these methods can add value in many cases.

My particular interest is in civil infrastructure systems like toll roads, water supply systems, and electricity transmission systems. From my experience in this course, consideration of flexibility and valuation of options would in many cases add value from a system designer or owner/operator’s perspective. In the case of public infrastructure systems especially, three characteristics stand out: the systems are typically tightly regulated; they may take years to construct and have even longer operating life spans; and their design, construction, and operation very often involve a complex web of actors with fragmented responsibility for the project and thus incomplete incentives to evaluate the system in a holistic manner (spatially and/or temporally). These characteristics shape the types of options that might be considered, and – in a general sense - I would be interested to explore further how they might constrain (or maybe expand) the range of viable options relative to a system with a single owner, as considered here.

The process of doing the application portfolio has been a valuable, if at times frustrating, learning experience. Although my project is similar to examples used in class, generating this particular case from scratch yielded a number of insights into the process of defining a system, identifying and gathering needed data, and applying the analysis techniques and led to a deeper understanding of the concepts than simply completing a pre-defined project would have. In particular, I believe I have a much better appreciation for the importance and difficulty of identifying “good” system concepts and, subsequently, options on (or in, though I did not use the latter) the systems.