Fort Carson, Colorado Solar Project: Incorporating Flexibility into Design

Application Portfolio By:

James Enos

Presented to:

Prof Richard de Neufville

Michel-Alexandre Cardin

Thomas Rand Nash

ESD.71 Engineering Systems Analysis for Design

Engineering Systems Division

Massachusetts Institute of Technology

Enos, James
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Executive Summary;

Fort Carson, which is located in Colorado Springs, Colorado, is considering building large solar fields to provide a percentage of the fort's electricity. This location is extremely attractive to solar designers because of the large amount of solar energy available in Colorado. The Fort Carson Solar Field Project could benefit from flexible designs in many different ways. First, incorporating uncertainty into the analysis of design alternatives leads to a more realistic forecast of what could happen over the life of the project. The major uncertainties of the price of electricity, annual insulation, and the demand for electricity have a profound impact on the value of this project.

Design Alternatives:

This report focuses on four design alternatives for the Fort Carson Solar Project. Design Alternative 1 is used as the base case for evaluation and does not incorporate any flexibility into the design. In this design alternative twenty-eight 10 MW_e, solar fields will be constructed in year 0 to accomplish the goal of producing 20% of Fort Carson's electricity from solar power. Design Alternative 2 incorporates flexibility in that, if the project does not meet predicted demand for two consecutive years, 2 additional solar fields would be constructed. Initially this alternative calls for 23 fields which would meet the demand for the first several years. Design alternative 3 also incorporates flexibility in the design; however, it uses an incremental growth model to meet the 20% goal by year 20. Initially, seven 10 MW_e fields are constructed, with seven additional fields being built every 5 years. The final design alternative only constructs one 10 MW_e field in year 0. Then, beginning at year 6, two additional fields are constructed annually until the 20% goal is met in year 20 of the project.

Decision Analysis:

The decision analysis section of this report focused on the uncertainty of the cost of construction for the solar fields. This could range from $6.25 per Watt to $3.30 per Watt at year 6 and will have an impact on the design of the project. Flexibility was introduced into the design based on this possibility. The decision analysis evaluated on the decision to continue to build solar fields per the design alternative or to not build any additional fields. The outcome of this decision analysis showed design alternative 4 to be the best design alternative with an ENPV of $633 (thousand). This is a vast improvement over design alternative 2, which was the best design when flexibility was not included with an ENPV of -$2,331 (thousand).

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Lattice Analysis

Additional flexibility was analyzed using a binomial lattice for the price of electricity. A price and probability lattice was developed from historical data that showed that the price of electricity grew at a rate of 3.51% with a standard deviation of 37%. Using this lattice, I evaluated a “call” option in the project to construct an additional 2 solar fields beginning in year 6. Using design alternative 4 as a base case where the cost of construction remained constant at $6.25 per Watt, I evaluated the option to build which takes advantage of possible up-side gains when the cost of electricity is high. Again, the flexibility of this “call” option increased the ENPV of the project from $1,498 to $3,898.

Recommendation

Based on this analysis, Fort Carson’s Solar Field Project is economically feasible. The design alternative that I would recommend for the project is design alternative 4. This alternative initially consists of one 10 MW_e field and builds additional fields beginning in year 6. With this alternative, Fort Carson should execute the decision to build additional fields at a rate of 2 per year beginning in year 6 if the price of a solar field drops to $3.30. This decision is based on the data presented in the decision analysis. If the price of a solar field does not drop, Fort Carson may still decide to build an additional 2 solar fields beginning in year 6, if the price of electricity is sufficiently high. This decision is based on the data presented in the lattice analysis.

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1. System Description:

The system that I will evaluate for economic feasibility is the integration of photovoltaic solar arrays into the power grid for a US Army Base, specifically, Fort Carson, CO. Fort Carson is located in Colorado Springs which receives over 300 days of sun in an average year. The intent for installing photovoltaic solar arrays is to meet a goal of producing 20% of Fort Carson's Energy from solar energy within 20 years.

This system will include the current power grid of Fort Carson and the power generation platform that they currently use. The baseline system that I will model will be a one-time installation of multiple large-scale photovoltaic arrays to off-set the current energy used by Fort Carson. All of the required collection equipment and the equipment required to integrate solar energy into the system will be included as costs for the system. Land will not be included in the cost of the system as the base has ample land available that is not being use for training and if they do pay for the usage of land that cost would not be affected by this project. There will not be a storage capacity associated with this system, so the solar system will only supply energy during the day and the remainder of the energy required will come from the current power generation plants. Therefore, the measurement of the systems effectiveness will be the amount of energy generated and the savings associated with that energy. The timeframe associated with this project will be 20 years, based on the fact that photovoltaic systems generally run essentially maintenance free for 10-30 years.

The benefactors of this project will be Fort Carson, effectively the US Government, the producers of the solar panels, and the environment. The economical benefits of this project will be reduced energy prices for the base; however, these will have to outweigh the initial costs of installing the system. A secondary economic benefit will be the purchase of a large-scale solar energy system by the government. The companies who build and install this equipment will benefit from the government contract and will have a large project to reference when marketing their project in the future. In addition to the economic benefits, there will also be a political benefit as the government will be able to show how they are "going green" in an effort to help avert global warming. This political benefit will be even more important in the eco-friendly environment of Colorado Springs.

Uncertainty Factors

For the Fort Carson Solar Project, I will focus on the uncertainty for the following variables: price of electricity ($/kWh), the demand for electricity (kWh), and the amount of electricity created by the solar panels (kWh). These three variables will have the most effect on the cost-benefit analysis for this project as they will influence the benefits associated with installing solar panels.

Price of Electricity:

The price of electricity is the major economic variable that will be uncertain as the project progresses. For this project we will utilize the Colorado Springs Utility rates for business that use over 6,000 kWh per month. There are recorded values of these rates since 2000. The utility company does charge a $0.61 / day fee for being attached to the grid; however I will not use this in the calculation of savings because Fort Carson would still be required to draw power from the utility department when the solar panels are not producing electricity.[1] See Table 1 below for historic values (all values in $/kWh)

Year	Supply Charge	Access Charge	Cost Adj.	Total Price
2000	$ 0.0274	$ 0.0236	$ 0.002368	$ 0.0534
2001	$ 0.0274	$ 0.0236	$ 0.003461	$ 0.0545
2002	$ 0.0274	$ 0.0236	$ 0.004003	$ 0.0550
2003	$ 0.0274	$ 0.0236	$ 0.005007	$ 0.0560
2004	$ 0.0280	$ 0.0243	$ 0.007765	$ 0.0601
2005	$ 0.0346	$ 0.0310	$ (0.0029)	$ 0.0627
2006	$ 0.0346	$ 0.0310	$ 0.0019	$ 0.0675
2007	$ 0.0346	$ 0.0310	$ 0.0082	$ 0.0738
2008	$ 0.0346	$ 0.0310	$ 0.0036	$ 0.0692

Table 1: Historic Electricity Prices ($ / kWh)

As shown in this table, these values are generally increasing at from 2003 to 2008. However, this variable is uncertain and could have a huge effect on the valuation of this project. After conducing a linear regression of the data in Table 1, the price of electricity is increasing at a rate of 3.51% annually with a standard error of 37%. These values will be used to estimate the cost of electricity during the monte-carlo simulation to account for uncertainty. The uncertainty for the price of electricity could be affected by economic, political, or technological variables that could drastically affect the price of electricity.

[1] Colorado Springs Utilities. "Business Rates."
<http://www.csu.org/customer/rates/rate_business/index.html> (26 September 2008)

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Demand for Electricity:

The demand of electricity could be considered an industrial variable that will change based on the number of units and personnel assigned to Fort Carson. This uncertainty stems from new regulations as well as technological and economic factors that could produce actual values far different than estimated values for the demand of electricity. I was unable to find an actual forecast for the increase in electricity consumption at Fort Carson, CO or a history of consumption. However, in 2007, I found that Fort Carson electricity usage was 138,000,000 kWh which gives a basis for starting a forecast. The EIA predicts that energy demand will increase by 0.7 % annually from 2006 to 2030.[2] So, we will use this as the estimated demand growth for Fort Carson. Like the price of electricity, the demand for electricity is another variable which has a high level of uncertainty. For this project, I will use a 50% degree of uncertainty. This will be crucial in determining how large to make the initial solar panel field as well as the number and size of supplemental solar panel fields.

Electricity Created

Although the amount of electricity created by the solar panels is based on the technology of the panels, this variable is also dependant on the amount of sunlight available for collection. The number of hours of sunlight at Fort Carson is the uncertain variable that will be used to determine the amount of electricity created by the solar panels. Historic averages for annual insulation are based on 30 years of data from Bolder, CO which is relatively close to Fort Carson and has approximately the same latitude. Table 2 below shows the monthly amount of total insulation, which can be used to calculate the amount of energy produced by the solar panels.[3] All values are in Langleys, which are equal to 41.86kJ/m^2.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
203	279	377	474	531	585	575	512	428	325	225	182

Table 2: Average Monthly Insulation

The amount of total insulation based on these averages is relatively certain. However, with changing weather conditions these values do have some degree of uncertainty. For this

[2] Energy Information Administration. “Annual Energy Outlook 2008 – Demand.” <http://www.eia.doe.gov/oiaf/aeo/demand.html> (29 September 2008)
[3] Tester, Drake, Driscoll, Goulay, and Peters. Sustainable Energy. Cambridge, MA, MIT Press, 2005. 554.

project I will assume that the insulation could decrease by up to 10% when calculating the amount of energy created and use these values as a maximum value.

These uncertain variables will give a more accurate forecast of how the system will perform and the actual savings. As uncertainty is introduced into the model for the solar panel system the NPV will change. Based on several thousand iterations of the model, a distribution of possible NPVs will evolve which will give decision makers the ability to decide on project options based on a level of certainty for success. Additionally, Expected Net Present Values (ENPV), or an average of the possible NPVs, can be used to evaluate possible variations to the project.

Other Model Parameters

I made several assumptions to set variables to calculate the NPV of the project. I determined the demand for solar energy by setting a goal of using solar energy for 20% of energy consumed. Without incorporating a large electrical storage module into this project it would be impossible to get 100% of Fort Carson's electricity from solar, which led me to setting the target of 20%. For NPV calculations, I used the government's nominal discount rate of 5.1% to calculate present values based on a 20 year project.

The size of the solar fields is set at 10 MW_e to base construction costs on the number of Watts produced, rather than the area of the solar field. This aligns with current cost estimates which are based on the solar field's rated capacity not the size of the field. These fields would have an area of 92,900 m^2 and currently cost $ 6,250,000.[4] I used efficiency for the solar panels of 24%, which is consistent with current photovoltaic panel technology which is being tested and deployed. NREL has achieved efficiencies of up to 40.8% with triple-junction solar cells, so an efficiency of 24% is very realistic.[5] Also, two credits for building solar fields were applied to the project. These credits are base on rebates given by Colorado Springs Utilities and the Federal Government to businesses that install solar energy systems. For this project, I assumed that Fort Carson would be eligible for these rebates as a customer of Colorado Spring Utilities even though they are a government agency. Both credits are based on building a 10 MW_e solar field and are applied in the year of construction. A solar refund of $37,500 ($3.75 per

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[4] National Renewable Energy Laboratory. "Photovoltaic Research Projects." July 25, 2008. <http://www.nrel.gov/pv/projects.html> (13 October 2008)

[5] NREL Newsroom. "NREL Solar Cell Sets World Efficiency Record at 40.8 Percent." August 13, 2008. <http://www.nrel.gov/news/press/2008/625.html> (13 October 2008)

Watt) and a solar tax credit of $1,875,000 (30% of construction costs) were deducted from construction costs.[6] The final assumption that I made to the project was to set the price of the renewable energy credit to $0.20 per kWh produced, which would have to be part of the contract with the electrical company to make this project beneficial to Fort Carson.

2. Defining Systems Design Alternatives:

For the Ft. Carson Solar Project, several different variables will affect the design alternatives for the project. I set the size of the solar field to a standard 10 MW_e and then determined the number of fields required to achieve the different intents of each option. Alternative 1 builds enough fields at Year 0 to ensure that the energy demand at Year 20 is met throughout the project's life. Alternative 2 builds an initial set of fields to meet the goal of 20% of demand produced by solar energy in Year 0 and then constructs an additional 2 fields if demand is not met for two consecutive years to maintain the 20% goal throughout the project's life. Alternative 3 incrementally builds fields based on achieving 5%, 10%, 15%, and 20% of electricity produced from solar energy at five year increments. The final alternative, builds one 10 MW_e field initially and then at Year 6 begins building two 10 MW_e fields annually to meet the 20% goal at Year 20 of the project.

Alternative 1 (Base Case)

The intent of the base case is to build enough 10 MW_e solar fields to meet the demand for electricity in 20 years during the initial year of the project. Using the standard size of 10 MW_e, the project requires 28 fields built in Year 0 to meet the predicted demand in Year 20.

Potential advantages of this alternative are that the solar fields will have an increased size which will take advantage of solar energy throughout the life of the project. Because the solar field's electricity production is only dependant on the area of the solar fields, this alternative will produce the most electricity over the life of the project. Since the project is not designed to meet 100% of demand, the amount of electricity produced is not limited to the demand. Therefore, the amount of money saved will be the greatest for this alternative because it produces the most electricity.

[6] Colorado Springs Utilities. "Renewable Energy Rebates." 2008 <http://www.csu.org/residential/rebates/renew_rebate/index.html> (13 October 2008)

Alternative 2 (Demand based Design)

The intent of the second alternative is to add flexibility into the design of the solar project to meet the 20% goal beginning in Year 0. If the project does not meet predicted demand for two consecutive years, then 2 additional solar fields would be constructed. Initially the project built 23 fields that were the standard size of 10 MW_e which would meet the demand for the first several years.

Potential advantages of this alternative are that initial costs are reduced because only 23 fields are constructed in Year 0 and additional construction costs are spread throughout the life of the project. Additionally, if construction costs are decreased or rebates increased in the future, this option will take advantage of these changes.

Alternative 3 (Incremental Growth)

The intent of the third alternative is to gradually increase the percentage of electricity coming from solar energy over the life of the project. For this alternative, the project produces 5% of Fort Carson's electricity from solar energy for the first 5 years, 10% for years 6-10, 15% for years 11-15, and 20% for years 16 to 20. This alternative meets the overall goal of producing 20% of Fort Carson's electricity from solar energy within 20 years. In this alternative, seven 10 MW_e fields were build in Year 0 and an additional 7 fields are added every 5 years for a total of 28 fields constructed. The schedule for deployment of this alternative is fixed in that 7 fields are built every 5 years; however, the Fort Carson could opt to suspend construction of additional fields.

Similar to Alternative 2, potential advantages of this alternative are smaller initial construction costs. Again this spreads construction costs through the life of the project to take advantage of the discount rate and possible improvements or cost reductions to the solar panels.

Alternative 4 (Build Small)

The fourth alternative for this project emerged during the decision analysis as a result of the chance event which occurs in Year 6 of the project. For this alternative, only one 10 MW_e is built in Year 0 and additional fields are build beginning in Year 6 of the project at a rate of two fields per year. This alternative will build a total of 28 solar fields over the lifetime of the project and will meet the 20% goal for solar energy by Year 20. The intent of this alternative is to give

Fort Carson the flexibility to build additional fields after Year 6 of the project when the expected costs of solar fields are projected to decrease by almost 50%.

Potential advantages of this design alternative are taking advantage of the possible cost reduction and delaying construction to later in the project's life. This alternative was specifically designed to take advantage of the possible reduction in expected costs of solar fields after Year 6. Additionally, by delaying construction until later in the project's timeline, Fort Carson will be able to take advantage of the discount rate when evaluating this project.

3. Decision Analysis:

The National Renewable Energy Laboratory (NREL) estimates that costs of photovoltaic solar arrays will decrease rapidly over the next 6 years. Current median cost for these systems is $6.25 per Watt as of 2000. The goal of the Department of Energy's Solar Energy Technology Program is to reduce costs of a system to $3.30 per Watt by 2015 (Year 6 of this project).[7] For the Decision Analysis at Year 6, I used the decrease in system cost as the chance event to evaluate the project. The first case assumed that the cost of a photovoltaic system remained the same at $6.25 per Watt, the second case assumed that cost were only reduced to $4.75 per Watt, and the third case assumed that the cost goal of $3.30 per Watt was met. For the decision analysis each of these cases were given equal probabilities of occurrence, or 1/3.

In Year 6, decision makers would be faced with two options. First, they could continue to build according to the alternative's plan. Or second, they could stop construction of additional solar fields. Obviously, both of these options have consequences associated with them. Possible consequences of choosing Option 1 would be losing money by adding additional solar fields. If they chose Option 2 and stopped construction they would fail to meet the goal of achieving 20% of electricity produced from solar energy. So, decision makers would have to decide if meeting the goal was more important or losing money on the project. For the decision analysis, I based my evaluation on the rational, economic decision to not continue building if the project would lose money.

Decision Tree Analysis

To evaluate these decisions, I compared the expected net present value (ENPV) of the four design alternatives based on the three chance cases described above. To take the

[7] National Renewable Energy Laboratory. "Photovoltaic Research Projects." July 25, 2008. <http://www.nrel.gov/pv/projects.html> (13 October 2008)

uncertainty associated with this project into account, I utilized a Monte Carlo simulation and ran the model 500 times for each case. This considered uncertainty for demand growth, price of electricity, and solar insulation in the simulation. The average, or expected net present value was then used to compare the different options and decisions that could be made at Year 6. Figure 1 shows the decision tree for this project.

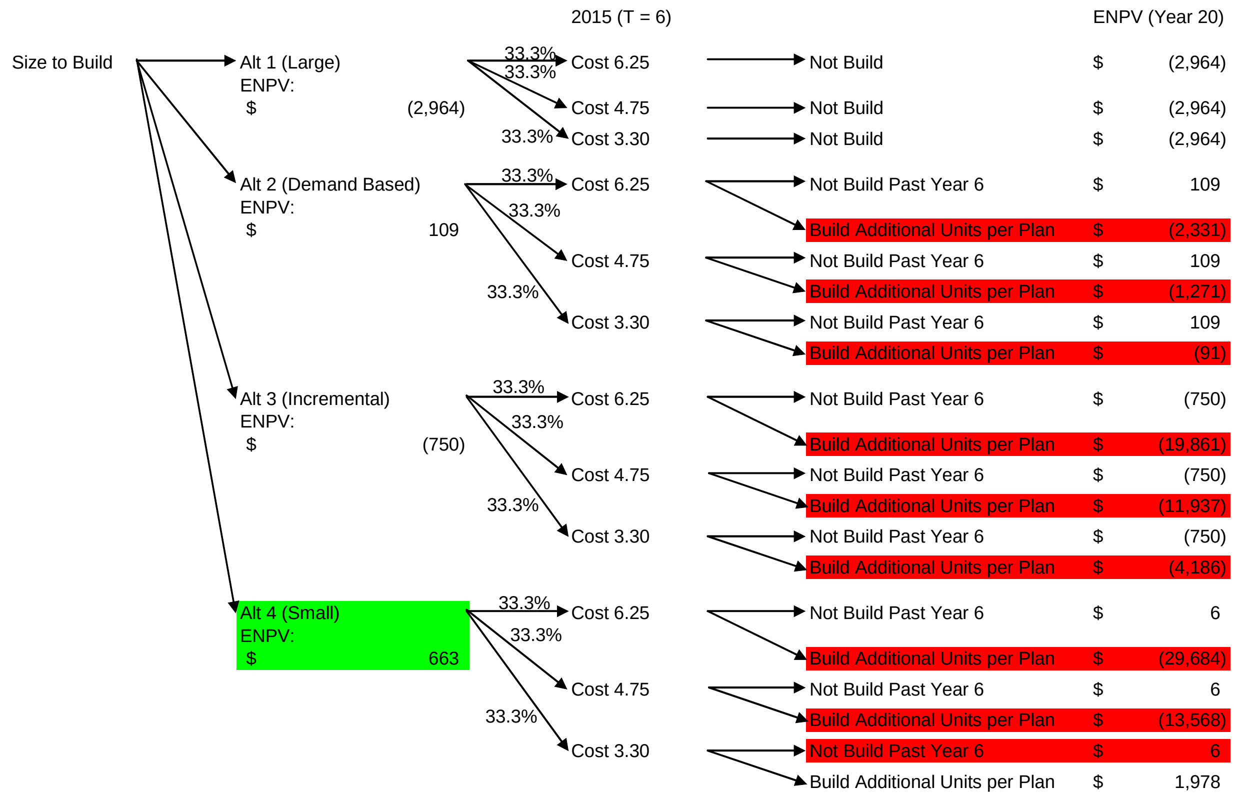

Figure 1: Decision Tree Analysis

Based on this decision analysis Alternative 4 is the best design for the Fort Carson Solar Project with an ENPV of $ 633 (thousand). Although this alternative was originally the worst option, with an ENPV of -$29,684 (thousand) it takes advantage of the possible decrease in price at Year 6. An additional advantage of this alternative is that the lowest ENPV of the project is $6 (thousand), so the project will not lose money if additional solar fields are not constructed after Year 6.

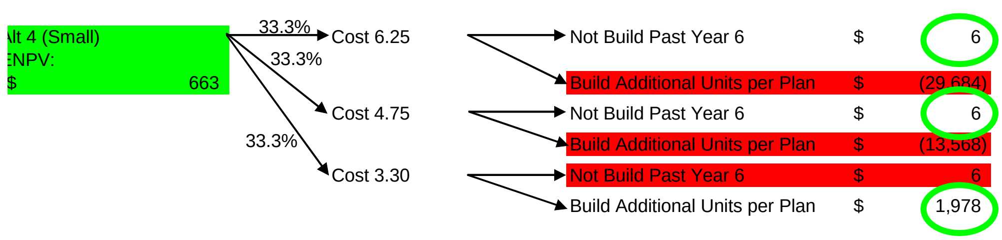

Figure 2: Alternative 4 Analysis

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Alternative 2, which was the best project after initial evaluation with an ENPV of -$2331 thousand dollars, becomes the second best design because it does not take full advantage of the possible decrease in solar field costs after Year 6.

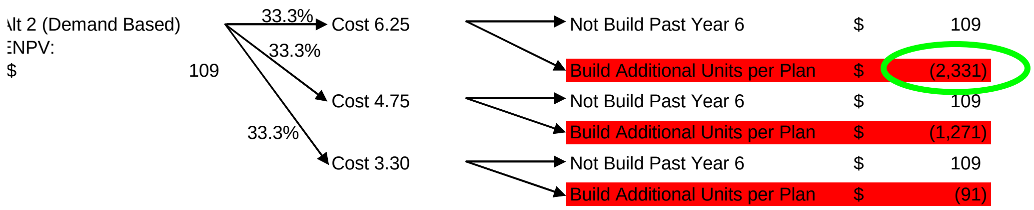

Figure 3: Alternative 2 Analysis

Design Alternative Analysis

Based on the Decision Tree Analysis, I conducted further analysis of each of the design alternatives based on the possible outcomes of the chance event in Year 6. Using the NPVs calculated during the decision tree analysis, I constructed a cumulative distribution function to show the value at risk and gain (VARG). Figure 4 presents the VARG function of the possible design alternatives.

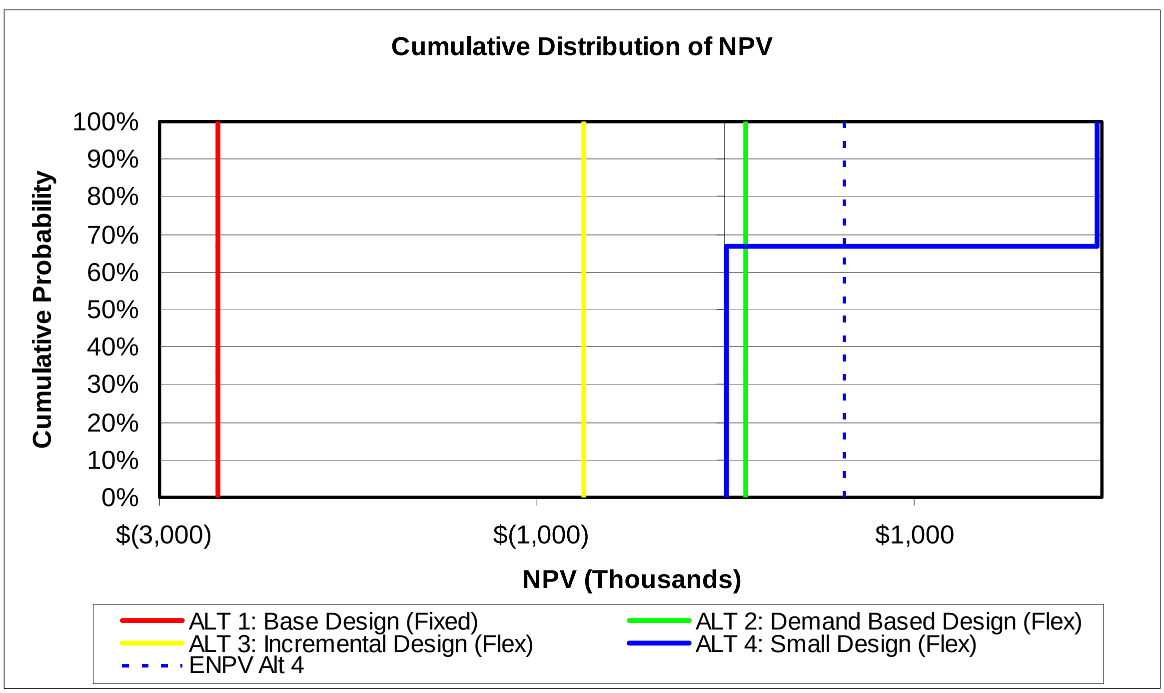

Figure 4: CDF of Design Alternatives

For Alternative 1, 2, and 3, the NPVs are constant at -$2,964 thousand, $109 thousand, and -$750 thousand respectively. This is because Alternative 1 has no flexibility build into the design and the NPV remains fixed. Although alternatives 2 and 3 have flexibility build into the design, the decision maker would never take advantage of this because the option to stop construction is always better than the option to continue to build. Alternative 4, takes full advantage of the decrease in price, so the upside gains are very large. The downside risk for Alternative 4 is not as small as it is for Alternative 2; however, it is much greater than Alternative 1 and 3. Both these factors are what make the ENPV of Alternative 4 large and show why this is the best design alternative.

Additional information for decision makers is provided in Table 3, which displays the ENPV, Maximum NPV, Minimum NPV, and Initial capital expenditures of each design alternative. Again, Alternative 4 is the best option for three out of four of the criteria. It has the largest maximum NPV which would be attractive to decision makers consider making a large profit most important. Also, it has the lowest initial capital expenditures which would be attractive to decision makers who do not want to risk a large amount of money for this project. Although Alternative 2 has a larger minimum NPV, this does not offset the possible gains associated with the large maximum NPV of Alternative 4. The smaller minimum NPV of Alternative 4 does not make this design unattractive because it is still positive.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Best Choice
ENPV	$ (2,694)	$ 109	$ (750)	$ 633	Alternative 4
Max NPV	$ (2,694)	$ 109	$ (750)	$ 1,978	Alternative 4
Min NPV	$ (2,694)	$ 109	$ (750)	$ 6	Alternative 2
Initial CAPEX	$ (121,450)	$ (99,763)	$ (30,363)	$ (4,338)	Alternative 4

Table 3: Decision Analysis Data

4. Lattice Analysis:

In the decision analysis, the option to take advantage of the possible reduction in construction cost from $6.25 per Watt to $3.30 per Watt was evaluated. For the lattice analysis, I will examine the possibility of executing an option to build additional fields depending on the cost of electricity, which determines how much Fort Carson would save in electricity costs. For this analysis, I will use Design Alternative 4 as a base; in which only 1 solar field is initially constructed and additional fields will only be built to take advantage of an increase in the cost of electricity per kilowatt-hour. This analysis will take advantaged of additional upside gains that could improve the minimum NPV of Alternative 4 if the price of the solar field remains constant at $6.25 per Watt as in the first case of the decision analysis.

To evaluate Design Alternative 4 further, I will use a lattice analysis for the uncertainty associated with the price of electricity. Based on the historical data provided by Colorado Springs Utilities, the price of electricity at Time 0 is 6.92 cents / kWh, the growth rate is 3.51% and the volatility is 37.0% per year. The linear regression plot is displayed in Figure 5. These values yield an upside factor of 1.448, a downside factor of 0.691 and an upside probability of 54.74%. Using this binomial lattice analysis, I will evaluate a “call” option in the design to build and additional 2 solar fields beginning in year 6.

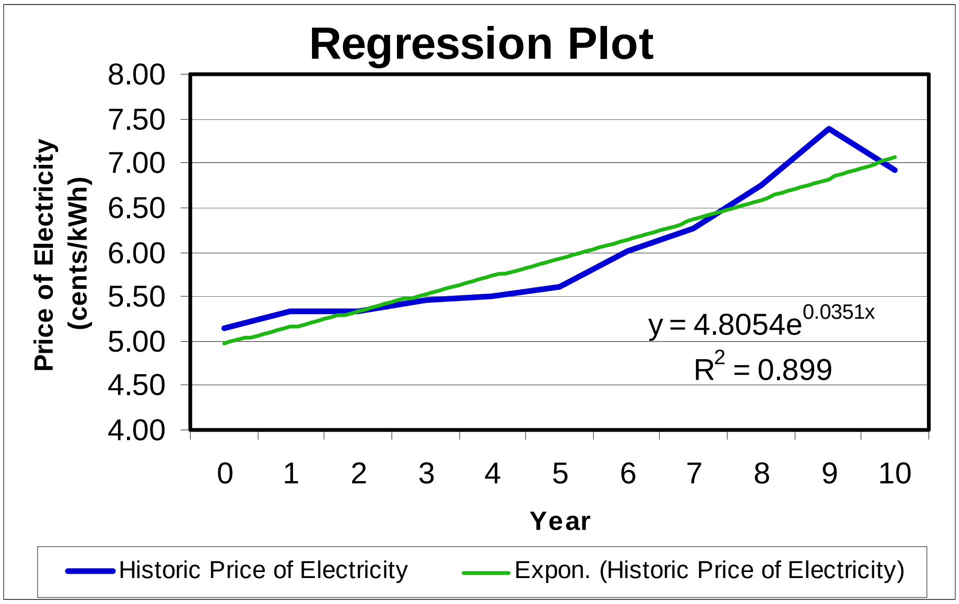

Figure 5: Regression Plot of Price of Electricity (cents/kWh)

Lattice Development

Using the upside factor, downside factor, and upside probabilities above, a binomial lattice was created for the price of electricity shown in Figure 6. Additionally, the probability lattice is shown in Figure 7.

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Price Lattice ($ / kWh)

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.07	0.10	0.15	0.21	0.30	0.44	0.64	0.92	1.34	1.93	2.80	4.05	5.87	8.49	12.30	17.80	25.77	37.31	54.01	78.20	113.21
	0.05	0.07	0.10	0.15	0.21	0.30	0.44	0.64	0.92	1.34	1.93	2.80	4.05	5.87	8.49	12.30	17.80	25.77	37.31	54.01
		0.03	0.05	0.07	0.10	0.15	0.21	0.30	0.44	0.64	0.92	1.34	1.93	2.80	4.05	5.87	8.49	12.30	17.80	25.77
			0.02	0.03	0.05	0.07	0.10	0.15	0.21	0.30	0.44	0.64	0.92	1.34	1.93	2.80	4.05	5.87	8.49	12.30
				0.02	0.02	0.03	0.05	0.07	0.10	0.15	0.21	0.30	0.44	0.64	0.92	1.34	1.93	2.80	4.05	5.87
					0.01	0.02	0.02	0.03	0.05	0.07	0.10	0.15	0.21	0.30	0.44	0.64	0.92	1.34	1.93	2.80
						0.01	0.01	0.02	0.02	0.03	0.05	0.07	0.10	0.15	0.21	0.30	0.44	0.64	0.92	1.34
							0.01	0.01	0.01	0.02	0.02	0.03	0.05	0.07	0.10	0.15	0.21	0.30	0.44	0.64
								0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.05	0.07	0.10	0.15	0.21	0.30
									0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.05	0.07	0.10	0.15
										0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.05	0.07
											0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.03
												0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02
													0.00	0.00	0.00	0.00	0.00	0.00	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	0.00	0.00
																0.00	0.00	0.00	0.00	0.00
																	0.00	0.00	0.00	0.00
																		0.00	0.00	0.00
																			0.00	0.00
																				0.00

Figure 6: Binomial Lattice for Price of Electricity

Probability Lattice

1.000	0.547	0.300	0.164	0.090	0.049	0.027	0.015	0.008	0.004	0.002	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.453	0.496	0.407	0.297	0.203	0.134	0.085	0.053	0.033	0.020	0.012	0.007	0.004	0.003	0.001	0.001	0.001	0.000	0.000	0.000
		0.205	0.336	0.368	0.336	0.276	0.211	0.154	0.109	0.074	0.050	0.033	0.021	0.014	0.009	0.005	0.003	0.002	0.001	0.001
			0.093	0.203	0.278	0.304	0.291	0.255	0.210	0.164	0.123	0.090	0.064	0.045	0.031	0.021	0.014	0.009	0.006	0.004
				0.042	0.115	0.189	0.241	0.264	0.260	0.237	0.204	0.167	0.132	0.102	0.076	0.055	0.040	0.028	0.019	0.013
					0.019	0.062	0.119	0.174	0.215	0.235	0.236	0.222	0.197	0.168	0.138	0.110	0.085	0.065	0.048	0.035
						0.009	0.033	0.072	0.118	0.162	0.195	0.214	0.217	0.208	0.190	0.166	0.141	0.116	0.092	0.072
							0.004	0.017	0.042	0.077	0.115	0.151	0.180	0.197	0.202	0.196	0.183	0.164	0.142	0.120
								0.002	0.009	0.024	0.048	0.078	0.111	0.142	0.167	0.183	0.189	0.186	0.176	0.161
									0.001	0.004	0.013	0.029	0.051	0.078	0.107	0.134	0.156	0.171	0.178	0.177
										0.000	0.002	0.007	0.017	0.032	0.053	0.078	0.103	0.127	0.147	0.161
											0.000	0.001	0.004	0.010	0.020	0.035	0.054	0.076	0.099	0.121
												0.000	0.001	0.002	0.006	0.012	0.022	0.037	0.055	0.075
													0.000	0.000	0.001	0.003	0.007	0.014	0.024	0.038
														0.000	0.000	0.001	0.002	0.004	0.009	0.016
															0.000	0.000	0.000	0.001	0.002	0.005
																0.000	0.000	0.000	0.000	0.001
																	0.000	0.000	0.000	0.000
																		0.000	0.000	0.000
																			0.000	0.000
																				0.000

Cumulative Probability

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

Figure 7: Probability Lattice

The possible prices of electricity at the end of year 20 are illustrated in Figure 8. This graph is extremely skewed to the left which shows that the price of electricity is more likely to remain low, with an average of $0.51. However, there is a small chance that the price could increase to around $113.21 per kWh.

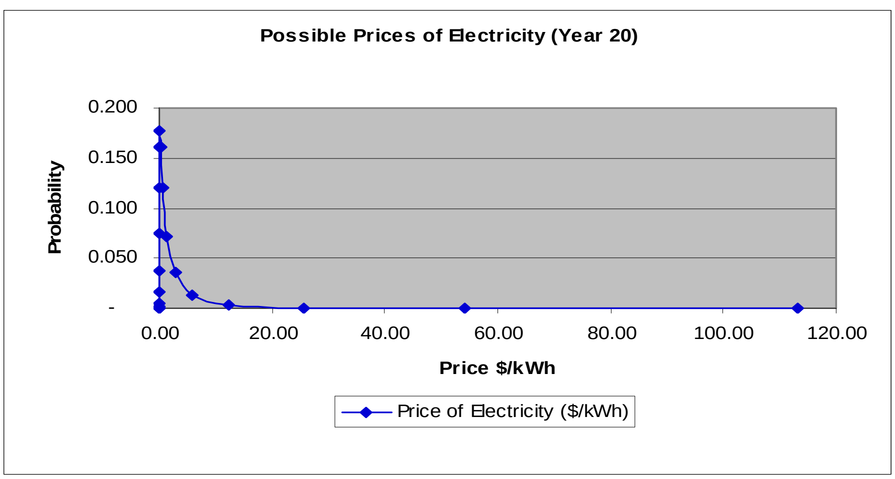

Figure 8: Possible Electricity Prices (Year 20)

Lattice Valuation

Using the lattice developed for the price of electricity, a model was developed to determine when to exercise an option to build 2 additional solar fields after Year 6 if the cost of construction remained at $6.25 per Watt. This model utilized dynamic programming, examining the cash-flows from the next year to determine the value of exercising this option. The "strike price," K, for this option is equivalent to the price of construction less the federal solar tax credit and solar energy refund from the electricity company for the two solar fields.

$$K = 2 * (\$6,250,000 - \$1,875,000 - \$37,500) = \$8,675,000$$

Then, using dynamic programming, the decision to exercise the option was modeled for the life of the project. The decision to expand the project was exercised if the present value of the expanded design less the strike price was greater than present value of the option design. Mathematically represented as:

$$\text{If: } PV_x(\text{Expanded Design}) - K > PV_x(\text{Option Design}) \text{ Then: Expand}$$

To determine the present values of the two design using dynamic programming the probabilities of the price of electricity going up or down were used to fold back the present value from the next time period. Mathematically represented as: (PV: Present Value, CF: Cash Flows)

$$PV_x(CF) = (Prob_{up} * PV_{x+1}(CF\ Up) + Prob_{down} * PV_{x+1}(CF\ Down))/(1+r) + CF_x$$

An example of this is shown in Figure 9, which is taken from top row at year 11 in the larger model shown in Figure 13. At this point, the option to expand would be exercised because 133,314 > 126,249. (Values expressed in thousands of dollars) The calculation for the Expanded Design is as follows:

$$PV_{10}(\text{Expanded Design}) = (54.75\% * 188,772 + 45.26\% * 93,078)/(1+.051) + 3,584 = 141,981$$

Because this example the option to expand is exercised the strike price must be subtracted from the Present Value to get the actual Present Value for that time period.

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PV_{10}(Expanded Design) – K = 141,989 – 8,675 =133,314

PV 10 (Expand Design)			PV 10 (Option Design)	
10	**11**		**10**	**11**
133,314	188,772	**>**	$ 126,249	$ 169,938
	93,078			$ 79,306

Figure 9: Example of “Expand” decision point

An example the decision not to expand is shown in Figure 10, is taken from the bottom row at year 11 as shown in Figure 13. At this point, the option to expand would not be exercised because -2,871 < 2,095. (Values expressed in thousands of dollars)

PV 10 (Expand Design)			PV 10 (Option Design)	
10	**11**		**10**	**11**
(2,871)	5,873	**<**	$ 2,095	$ 1,958
	5,815			$ 1,938

Figure 10: Example of "Not Expand" decision point

Using the lattice method for determining the price of electricity, NPV of the fixed design is $1,506 (thousand) over the live of the project. This valuation becomes the base for determining the present value for the option design. Figure 11 illustrates the present values of the cash flows for the life of the project for the fixed design. When the option to expand is evaluated, you begin in a fixed design state and then determine if it would be better to have a fixed design or an expanded design using the method outlined above. Using this as a base is evident in that the Cash Flows for year 20 are the same in the fixed design and the option design in Figure 13.

PV (Cash Flows)
Fixed Design
(thousands)

0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1,509	7,092	8,344	10,022	12,261	15,218	19,101	24,169	30,729	39,110	49,719	62,924	79,093	98,443	120,950	145,661	170,557	191,973	203,418	191,021	$134,687
	5,000	5,548	6,298	7,313	8,667	10,460	12,816	15,882	19,812	24,802	31,026	38,661	47,809	58,460	70,158	81,938	92,054	97,409	91,381	$ 64,385
		4,214	4,521	4,952	5,541	6,337	7,400	8,798	10,605	12,914	15,807	19,370	23,651	28,645	34,134	39,657	44,381	46,830	43,842	$ 30,843
			3,673	3,826	4,050	4,370	4,815	5,418	6,212	7,242	8,546	10,166	12,124	14,420	16,947	19,484	21,636	22,699	21,160	$ 14,840
				3,288	3,338	3,432	3,582	3,806	4,116	4,536	5,082	5,774	6,625	7,633	8,746	9,859	10,784	11,185	10,338	$ 7,205
					2,999	2,984	2,994	3,036	3,116	3,244	3,429	3,679	4,001	4,395	4,834	5,267	5,606	5,692	5,175	$ 3,562
						2,770	2,713	2,669	2,639	2,628	2,640	2,679	2,749	2,850	2,967	3,076	3,135	3,071	2,711	$ 1,823
							2,579	2,494	2,411	2,334	2,264	2,202	2,152	2,113	2,076	2,031	1,957	1,820	1,536	$ 994
								2,411	2,303	2,194	2,084	1,975	1,867	1,761	1,652	1,532	1,394	1,224	975	$ 599
									2,251	2,127	1,999	1,866	1,731	1,594	1,449	1,294	1,126	939	708	$ 410
										2,095	1,958	1,815	1,666	1,514	1,352	1,180	998	803	580	$ 320
											1,938	1,790	1,635	1,475	1,306	1,126	937	738	519	$ 277
												1,778	1,620	1,457	1,284	1,100	908	708	490	$ 256
													1,613	1,448	1,273	1,088	894	693	476	$ 246
														1,444	1,268	1,082	887	686	470	$ 242
															1,266	1,079	884	682	466	$ 240
																1,078	883	681	465	$ 238
																	882	680	464	$ 238
																		680	464	$ 238
																			464	$ 238
																				$ 238

Figure 11: PV of Cash Flows (Fixed Design)

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Figure 12 shows the decision to exercise the call option to expand over the life of the project. The decision does not apply to the first five years of the project based on design alternative four's parameters which would only begin building new solar fields beginning at year 6. As shown in Figure 12, this option is executed when the price of electricity is high and savings from additional electricity production outweigh the cost of construction.

Exercise Expand Option

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
N/A	N/A	N/A	N/A	N/A	N/A	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	N/A	N/A	N/A	N/A	N/A	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
		N/A	N/A	N/A	N/A	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
			N/A	N/A	N/A	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
				N/A	N/A	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES
					N/A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
						NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
							NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
								NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
									NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
										NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
											NO	NO	NO	NO	NO	NO	NO	NO	NO
												NO	NO	NO	NO	NO	NO	NO	NO
													NO	NO	NO	NO	NO	NO	NO
														NO	NO	NO	NO	NO	NO
															NO	NO	NO	NO	NO
																NO	NO	NO	NO
																	NO	NO	NO
																		NO	NO
																			NO

Figure 12: Decision to exercise call option to expand

The method described in Figure 9 and 10 to determine the present value of the expand option is used throughout the life cycle of the project and yields a much higher NPV than the fixed design. Utilizing the same dynamic programming method with the option to expand to 3 solar fields beginning in year 6, the NPV for the project is $3,922 (thousand). The model for the project with the expand option is shown in Figure 13. Therefore, the value of the option to expand in year 6 of the project is $2,416 thousand.

**PV (Cash Flows)
Expand Option
(thousands)**

5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
$34,321	$46,641	$61,184	$79,859	$103,590	$133,314	$169,938	$214,144	$266,113	$324,437	$385,228	$441,145	$479,095	$472,435	$378,103	$134,687
$15,792	$21,509	$28,263	$36,979	$ 48,096	$ 62,061	$ 79,306	$100,158	$124,704	$152,268	$180,994	$207,380	$225,184	$221,686	$176,341	$ 64,385
$ 7,402	$ 9,518	$12,556	$16,520	$ 21,619	$ 28,066	$ 36,065	$ 45,774	$ 57,235	$ 70,124	$ 83,551	$ 95,848	$104,039	$102,050	$ 80,077	$ 30,843
$ 4,312	$ 4,845	$ 5,674	$ 6,966	$ 8,987	$ 11,846	$ 15,434	$ 19,826	$ 25,045	$ 30,932	$ 37,060	$ 42,634	$ 46,239	$ 44,970	$ 34,149	$ 14,840
$ 3,356	$ 3,465	$ 3,646	$ 3,929	$ 4,352	$ 4,989	$ 5,953	$ 7,446	$ 9,687	$ 12,233	$ 14,878	$ 17,245	$ 18,662	$ 17,736	$ 12,236	$ 7,205
$ 2,999	$ 2,984	$ 2,994	$ 3,036	$ 3,116	$ 3,244	$ 3,429	$ 3,679	$ 4,001	$ 4,395	$ 4,834	$ 5,267	$ 5,606	$ 5,692	$ 5,175	$ 3,562
	$ 2,770	$ 2,713	$ 2,669	$ 2,639	$ 2,628	$ 2,640	$ 2,679	$ 2,749	$ 2,850	$ 2,967	$ 3,076	$ 3,135	$ 3,071	$ 2,711	$ 1,823
		$ 2,579	$ 2,494	$ 2,411	$ 2,334	$ 2,264	$ 2,202	$ 2,152	$ 2,113	$ 2,076	$ 2,031	$ 1,957	$ 1,820	$ 1,536	$ 994
			$ 2,411	$ 2,303	$ 2,194	$ 2,084	$ 1,975	$ 1,867	$ 1,761	$ 1,652	$ 1,532	$ 1,394	$ 1,224	$ 975	$ 599
				$ 2,251	$ 2,127	$ 1,999	$ 1,866	$ 1,731	$ 1,594	$ 1,449	$ 1,294	$ 1,126	$ 939	$ 708	$ 410
					$ 2,095	$ 1,958	$ 1,815	$ 1,666	$ 1,514	$ 1,352	$ 1,180	$ 998	$ 803	$ 580	$ 320
						$ 1,938	$ 1,790	$ 1,635	$ 1,475	$ 1,306	$ 1,126	$ 937	$ 738	$ 519	$ 277
							$ 1,778	$ 1,620	$ 1,457	$ 1,284	$ 1,100	$ 908	$ 708	$ 490	$ 256
								$ 1,613	$ 1,448	$ 1,273	$ 1,088	$ 894	$ 693	$ 476	$ 246
									$ 1,444	$ 1,268	$ 1,082	$ 887	$ 686	$ 470	$ 242
										$ 1,266	$ 1,079	$ 884	$ 682	$ 466	$ 240
											$ 1,078	$ 883	$ 681	$ 465	$ 238
												$ 882	$ 680	$ 464	$ 238
													$ 680	$ 464	$ 238
														$ 464	$ 238
															$ 238

Figure 13: PV Cash Flows (Option to expand beginning in year 6)

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The three design alternatives presented in the lattice analysis are compared below in Table 4. These are all variations of the project design alternative 4. The first design is the fixed design with 1 solar field constructed in year 0. The second design alternative is the expanded design option, in which the project is expanded to 3 solar fields in year 6. The final design alternative includes the option to expand based on the next year's cash flows.

Design Alternative	ENPV
4a: Fixed Design	$1,506
4b: Expanded Design	$3,183
4c: Option to Expand Design	$3,922
Best Alternative	Option to Expand

Table 4: Decision Table

Lattice VARG Analysis

The lattice analysis above focuses on the estimated, or mean, net present value of the fixed, expanded, and option designs. To further examine the possible net present values, I conducted an analysis of the VARG. This analysis was conducted over the first 10 years of the project and evaluates the possible NPVs based on the probability of the outcome. Figure 14 shows the cumulative distribution of the net present values for the designs. It is important to note that the values of the 10 year analysis differ from the values for the 20 year project because they do not take into account any revenues or costs past year 10.

There are 1024 possible paths for this lattice analysis over the 10 year period. Evaluating these paths will provide a cumulative distribution to gain a better understanding of the possible outcomes for this project. Table 5 provides examples of the paths for the Expand Option design for the three possible scenarios: scenario 1 expands in year 6, scenario 2 expands in year 9, and scenario 3 does not expand based on the possible prices of electricity.

	PV (Cash Flows)											Option
Path #	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**NPV**
		u	u	u	u	u	u	u	u	u	d	Expand 6
2	$(4,338)	$ 342	$ 371	$ 418	$ 489	$ 593	$(5,705)	$ 2,814	$ 3,666	$ 4,804	$ 3,341	$ 6,795
		u	u	d	d	u	d	u	u	u	u	Expand 9
209	$(4,338)	$ 342	$ 371	$ 306	$ 261	$ 278	$ 235	$ 251	$ 275	$(5,237)	$ 1,097	$ (6,159)
		u	d	u	u	d	d	u	u	d	d	Not Expand
308	$(4,338)	$ 342	$ 290	$ 306	$ 335	$ 278	$ 235	$ 251	$ 275	$ 225	$ 195	$ (1,606)

Table 5: Example of Lattice Paths

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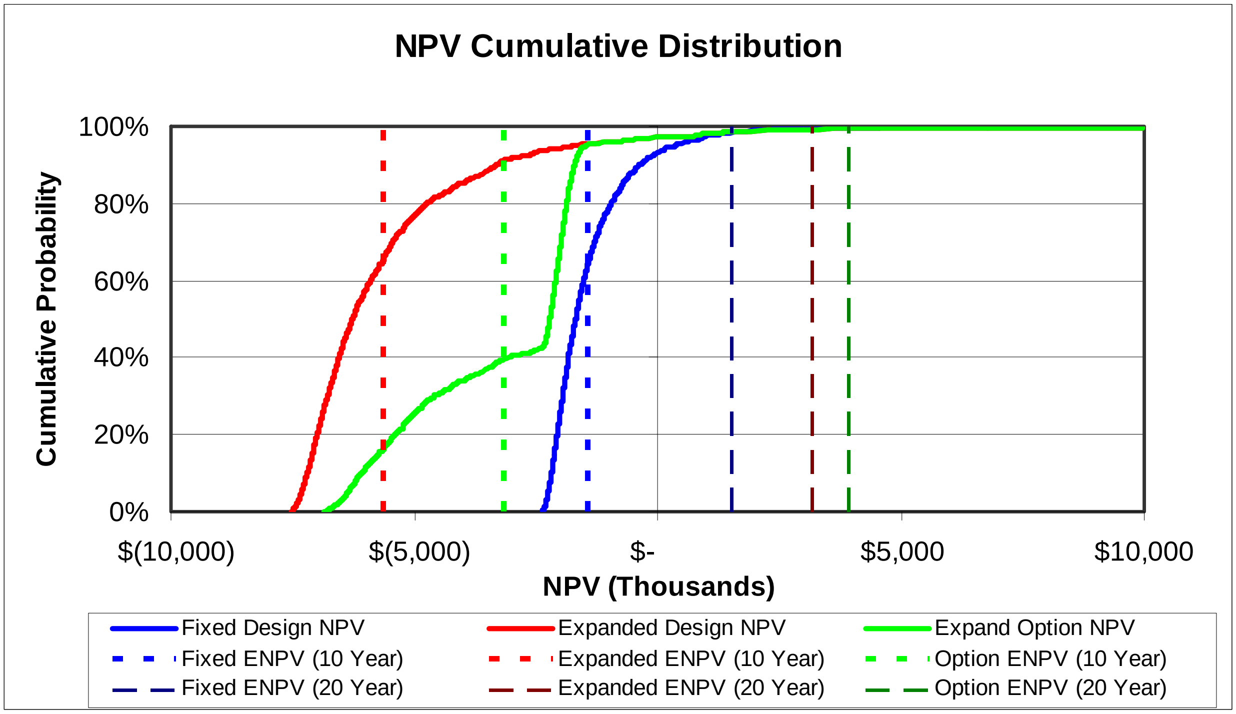

Figure 14: NPV Cumulative Distribution

Additionally, the analysis of the VARG yields several other variables to evaluate the design alternatives. As shown in Table 6, the 10 year ENPV, 20 year ENPV, Max NPV, and Min NPV were determined for each alternative. In this analysis, the fixed option yielded the best 10 year ENPV and Min NPV. This could be attributed to only analyzing the first 10 years of the project because the fixed design does not have any additional costs from year 1 to 10. The design alternative with the option to expand yields the highest Max NPV and 20 year ENPV.

	Fixed	Expanded	Option	Best Design
ENPV (10 Year)	$ (1,423)	$ (5,610)	$ (3,154)	Fixed
ENPV (20 Year)	$ 1,506	$ 3,183	$ 3,922	Option
Max NPV	$ 4,543	$ 9,980	$ 9,980	Expand/Option
Min NPV	$ (2,360)	$ (7,533)	$ (6,847)	Fixed

Table 6: Multi-Variable Decision Data

Although these values indicated that the fixed design and the option to expand design are both the best design for two of the multi-variable decision factors, I would still recommend the option to expand design. This analysis failed to account for revenues from year 11 to 20, which could increase the net present value of the option design at a larger rate than the fixed design.

5. Conclusion:

Based on analysis conducted in this report, Fort Carson's Solar Field Project is economically feasible. The design alternative that I would recommend for the project is design alternative 4. This alternative initially consists of one 10 MW_e field and builds additional fields beginning in year 6. With this alternative, Fort Carson should execute the decision to build additional fields at a rate of 2 per year beginning in year 6 if the price of a solar field drops to $3.30. This decision is based on the data presented in the decision analysis. If the price of a solar field does not drop, Fort Carson may still decide to build an additional 2 solar fields beginning in year 6, if the price of electricity is sufficiently high. This decision is based on the data presented in the lattice analysis.

In completing this application project, I have gained a better understanding of how to apply the tools presented in class to a real-world project. Both the decision analysis and lattice analysis account for uncertainty which is inherent in any project in a manner that I had not considered before. As is common practice, I too fell into the trap of disregarding the complexity of uncertainty when evaluating projects. For example, it is much easier and generally considered acceptable to take the average growth rate of the price of electricity as a constant and analyze a project with this fixed variable. However, by applying a tool such as the lattice analysis to this same problem, designers gain a much better perspective on possible realities for their project. This leads to developing flexible designs which enable engineers to take advantage of possible gains if the situation is better than expected or avoid losses if the situation worsens.

In general the application portfolio solidified the concepts presented in class and provided an outstanding example of how accounting for uncertainty and incorporating flexibility can increase a system's performance. The lectures throughout the semester were outstanding in presenting the material and providing us with the tools to evaluate designs. However, the application portfolio allows students to apply these tools and learn through doing the actual analysis on a project of our own choosing. This emphasizes how these tools can be applied to a broad spectrum of projects. I felt the manner in which the application portfolio was submitted for reviews throughout the semester was greatly helpful. First, it allowed us to utilize a tool that was recently presented in a lecture. Also, the feedback from the TAs allowed me to realize if I truly understood a topic or sent me in the right direction if I did not have a good grasp of the tools. The one area in which I wish we had more time to explore would be the lattice VARG and methods to evaluate this. It felt rushed at the end of the semester and I would have liked more time to examine this topic.

Overall, I found the application portfolio to be challenging and worthwhile. I cannot think of a better way to show students the paradigm change from traditional design to designing for uncertainty by incorporating flexibility.