Real Option Analysis of a Large-scale Space Solar Power Venture

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Abstract

This study values a large-scale Space Solar Power (SSP) venture by using Real Option Analysis (ROA), an advanced financial technique that takes managerial flexibility into account. We develop a model to represent the entire project as a series of decisions in a binomial tree. We calibrate the tree using data from energy markets as well as Monte Carlo simulations of the distribution of project value under expected conditions. In the end, specific sources of flexibility are formulated as Real Options within the binomial tree and the calculated value of these options is added to the Net Present Value (NPV) of the project. Unlike previous studies that argue SSP is economically unfeasible, we conclude that large-scale SSP is a viable business venture as long as the project is implemented in stages and real options are exercised optimally. Previous studies on the economic feasibility of SSP have used only static Discounted Cash Flow (DCF) models, which assume that a project will be carried out until completion under any circumstances. Our study, on the other hand, incorporates the flexibility to enter or abandon the project in response to energy prices, launch costs, and other technological parameters that affect the viability of the project. Modern decision analysis tools demonstrate that such flexibility adds tremendous value to a venture facing large uncertainties, as is the case with SSP.

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I. Introduction

Space Solar Power (SSP) is a technology that collects solar power on satellites in space and wirelessly transfers this power for use on Earth. The initial idea, known as "Satellite-Solar Power System (SSPS)" was first described in November 1968. At the time, however, SSP faced major technological challenges that prevented it from becoming a feasible source of energy. In 1973, Peter Glaser carried the concept of SSP closer to reality by inventing the method of transmitting power over long distances using microwaves (Glaser, 1973). He proposed the idea of transmitting solar power from a large antenna in orbit to a rectifying antenna on Earth (referred to as a "rectenna"), which would convert the waves to electricity.

Compared to other renewable energies, which are available only intermittently (i.e. hydro and wind energies), SSP is continuously available and reliable. A solar power satellite deployed into geostationary orbit can produce energy at peak power 99% of the time because it is directly lit by the Sun. The average daily energy reaching Earth's surface is only one tenth of that in orbit. In addition, ground solar power requires a large amount of land. The rectennas used for SSP are 90% transparent and can be built over farmland, water or strategic remote locations using conventional construction methods. Crops and farm animals may be raised underneath a rectenna, as the thin wire used for support only slightly reduces the sunlight.

Besides the advantages mentioned above, SSP is one of the few options that will meet the power demand of the fast-growing world economy. The 2007 National Security Space Office (NSSO, now called the DoD Executive Agent for Space) report states "A single kilometer-wide band of Geosynchronous Earth Orbit experiences enough solar flux in one year to nearly equal the amount of energy contained within all known recoverable conventional oil reserves on Earth today." (NSSO, 2007). Adapt from the benefit of collecting huge amount of energy in a short period of time, SSP may also be the answer to the long-term energy generation and climate control issues facing humanity. The report summarizes the attractive features of SSP relative to conventional energy sources and argues that SSP is the only option that is clean, safe, and reliable and can be used for base-load power, the amount of power required to meet minimum demands based on reasonable expectations of customer requirements. As a byproduct of SSP, carbon-neutral synthetic fuel could additionally be captured through three major steps (further explored in Section *IV.C Using SSP for Synthetic Fuel*) to help reduce the carbon footprint of the world economy.

Our study values a large-scale SSP venture by using Real Option Analysis (ROA), an advanced financial technique that takes flexibility into account. We extend the work of Atanasov and Lenard (2010), who apply ROA to a small-scale SSP system designed for high-end users, and focus on large-scale gigawatt-power SSP systems. We develop a model to represent the entire project as a series of decisions in a binomial tree, which is a graphical representation of the possible intrinsic values that an option may take at different nodes or time periods, and calibrate the tree using data from financial, energy, and other markets. In the end, specific sources of flexibility are formulated as real options within the binomial tree and the calculated value of these options is added to the Net Present Value (NPV) of the project.

After evaluating the numerous real options, we conclude that large-scale SSP is a viable business venture as long as the project is implemented in stages and real options are exercised optimally. Furthermore, we propose potential opportunities related to SSP ventures such as the valuation of obtaining construction materials from the Moon or the satellites of Mars as a non-conventional alternative to launching all components from Earth. The energy savings of obtaining material from extraterrestrial sources are compared with the estimated costs of constructing automated facilities to harvest this material. Our analysis calculates the critical scale of SSP systems, above which harvesting material from extraterrestrial sources dominates the traditional launch-from-Earth model. We also suggest possible future research using large-scale SSP to manufacture carbon-neutral synthetic fuels, which will undoubtedly lead to a reduction of our carbon footprint.

The remainder of the paper is structured as follows. The next section describes the background of SSP analysis, including previous economic analysis based on DCF models, followed by a background description of ROA and our research objectives. Section III first follows the traditional approach by calculating NPV using a DCF model, then adds back the hidden values of real options discovered from ROA to the project value. Section IV provides several thoughts on the financing aspect of such a venture, and explores the possibilities of reducing the large overhead costs by adopting alternative launching methods to reduce launch costs and harvesting synthetic fuel as a byproduct to claim more returns from such a venture. Section V concludes our paper. All details about our key assumptions are presented in the Appendix.

II. Background

II.A Previous Economic Analyses of SSP

Since the 1970s, a number of studies have analyzed the economic feasibility of SSP business ventures (Mankins, 1997; Macaulay et al, 2000; Xin et al, 2009). The consensus among these studies has been pointing at the large uncertainty about revenues and costs, the current lack of technology that makes SSP more expensive than current energy sources. Risk factors in these analyses give SSP an unattractive profile. However, there have been several major issues with previous economic analysis of SSP ventures.

These studies have used only traditional financial tools to value the projects, primarily static Discounted Cash Flow (DCF) models. Such valuation methodologies create problems because they assume that a project will be carried out until completion and excludes the uncertainties that may occur during the implementation (Charania & Olds, 2000). For example, a five-year project could involve the deployment of ten satellites overall, but not all ten of them have to be deployed at once. If, at the end of stage one, the first satellite encountered problems or more investment in R&D is required, a company has the flexibility to choose whether or not to continue with the project at that moment. DCF analysis does not capture such flexibility in valuing the feasibility of the project.

Due to the nature of the SSP, most people who value space business ventures have advanced technical knowledge, but use antiquated valuation methods. Most previous studies use static DCF methods to value the projects. The most basic of these is NPV (Net Present Value), which discounts future cash flows to the present. A positive NPV means that a project is worth pursuing. Similarly, IRR (Internal Rate of Return) looks at the future cash flows of a given project and determines the internal rate of return that is necessary for the project cash flows to break even. Unsurprisingly, most NPV and IRR valuations of SSP have resulted in largely negative valuations. Considering the large upfront costs of investing in such a project and the fact that potential payoffs would occur in the distant future, the risk profile of SSP in an all-or-nothing way would certainly be unattractive.

Modern decision analysis tools tell us that the flexibility to expand or abandon adds tremendous value to a venture, especially when it depends on large uncertainties, as in the case with space business ventures.

II.B Real Options Analysis

Real Option Analysis (ROA) is a technique that was originally developed for financial options and values the flexibility of having a right, rather than an obligation, to make a certain decision. ROA allows for the flexibility of making decisions in the future and potentially abandoning, expanding or waiting on a project (Joseph, 2005). If a project is not as successful as initially expected, the project can be abandoned, or production capacity can be reduced or suspended. In this case, the loss of capital is limited to initial investments and any incurred costs in the initial stages of the project (Copeland & Antikarov, 2003). Alternatively, if a project seems more promising, then growth strategies can be implemented to expand the venture or enter into new markets. Additionally, certain decisions that can be put off until uncertainty is resolved in the future can add value to a project. These potential values are not included in a static DCF model.

Real Option Analysis has particular applications in industries where there is a great deal of uncertainty. For example, the success of a pharmaceutical company's R&D project can highly depend on a number of factors that appear at various stages of the project. Although there may be a number of unknowns at the beginning of a process, using ROA, one can model reasonable ranges for the uncertainties and determine whether, all things considered, a project should be undertaken at anytime during the project. ROA also pervades in the energy sector, particularly oil and gas exploration. Since the profitability of an oil or gas venture is entirely dependent on the highly volatile prices of oil and gas in the market, DCF would be an unsatisfactory valuation method due to the difficulty in forecasting future cash flows. It also ignores the ability of companies to defer exploration or development decisions to the future (Lund, 1999). Though given the similar risk characteristics in oil, gas sector and SSP venture, only a small number of studies have used ROA in the analysis of space applications. The most prominent study of this type is Weck, Neufville & Chaize (2004), which analyzes the staged deployment of communication satellites.

Classic ROA models decisions to respond to a single source of uncertainty. When two or more sources of uncertainty are relevant to the project, the real options are called Rainbow Options (Kodukula & Papudesu, 2006). Rainbow Options are widely used to value natural resource deposits, which are usually exposed to two uncertainties – price and quantity (Smith & McCardle, 1999).

The two major sources of uncertainty that we take into consideration in this particular research project are 1) the present value of future revenues, which depends on future energy prices, and 2) the total cost of installation, which includes system cost, assembly expenses and launch expenses. We choose a five-years horizon for the model. This is approximately the time period after which power solar will become commercially available. For example, Solaren Corporation signed a contract, allowing PG&E to deliver energy from a new solar power project ("Project"), which is expected to complete in 2016 (PE&G, 2009). A longer horizon for the model will only increase the value of the option, so five years is a rather conservative time frame. In Year 5–the final period of our model – each terminal node of the tree for the SSP venture is evaluated and the project is only launched if the difference between the present value of revenues and total system costs is positive.

II.C Research Objectives

Our research overcomes several shortcomings of previous economic analyses. We develop a Real Options Analysis of a large-scale SSP system that explicitly accounts for flexibility to respond to resolution of uncertainty in the future. This is the first study to analyze a large- scale SSP venture for base-load power using ROA. We are also the first to analyze multiple sources of uncertainty in a large-scale SSP venture using the Rainbow Option framework. In addition, we provide a preliminary analysis of non-conventional alternatives, such as retrieving mass from the moon or the satellites of Mars as construction materials for the satellite.

III. Methodology

We use five basic steps in developing our ROA model. First, we follow the traditional approach and calculate the Net Present Value (NPV) of the project under no flexibility and baseline values of all parameters. Next, we use Crystal Ball to run Monte Carlo simulations on the variation in baseline NPV when each critical parameter is varied according to a given distribution. We run 20,000 trials of the Monte Carlo simulation in order to best represent the extent of various uncertainty situations. Although there are other methods available, we follow the Cox, Ross, and Rubinstein's option-pricing model (1979) because it is the most well established in dealing with binomial trees. The Binomial Options Pricing Model requires specific factors to determine the *Up* and *Down* movements, which are calculated by using an underlying volatility. For our Real Options Analysis, we use the standard deviation of the NPV from the simulations to build the binomial tree model. Step four involves using the binomial tree model to evaluate the option of expanding or abandoning the project in Year 5. Our final step involves transforming the simple option into a more complex Rainbow Option by taking into account another source of uncertainty—the total project cost. The nesting of the steps in the model allows us to directly compare the value of the project as calculated from three alternative approaches– 1) The classic NPV; 2) ROA with a single source of uncertainty; and 3) ROA of a Rainbow Option based on two sources of uncertainty.

III.A Baseline NPV Analysis

We first research the various inputs that affect costs and revenues for the project and build a model with the most logical assumptions for the inputs. Table I shows inputs representing the most likely or current scenarios that are built into the model to come up with an initial NPV. The variables highlighted in yellow (launch cost from GEO per kg; specific power density kg/kilowatt installed power; price per watt installed power; assembly cost per kg; price per kilowatt-hour; annual growth in price for electricity) are those that we later simulate in our NPV model. The annual growth in price for electricity follows a normal distribution, while we assume the other variables follow uniform distribution. For the purpose of this paper, it is important that we simulate the variables with large ranges of data to compensate for the lack of significant research on the proper ranges for the inputs. Research on most of the inputs cited inconsistent ranges that would not permit the use of normal distributions; thus, we used uniform distributions to conservatively account for the equally likely instances in each of the ranges. We did not simulate certain inputs that were found to be relatively standard in valuations of this nature, such as Annual Loss of System Output, etc., because of the consensus on these figures in recent literature. For example, a combined efficiency of 65% was found by taking the product of the efficiencies of electricity transfer over various stages from space to the rectennas, a 1% annual loss of system output, a useful life of 25 years, and a Balance of System (BOS) multiple of 2. The BOS multiple measures the combined weight of the system relative to the power generation system. In other words, the system mass (in kg) equals the power output multiplied by the power density and the BOS multiple of 2.

We set the cost of capital used to discount all future cash flow to 10%. Cash flows are projected for the useful life of 25 years, with annual revenues equal to the product of *power output*, *24* hours/day, *365* days/year, (1 - the *annual loss* in the system of 1%), the *price per kilowatt-hour* (which, due to the variance, we model different ranges for), (*1* + the *growth in price* of electricity) to the power of (time), *percent* of time active and the combined *efficiency.*

The output in Table II shows the breakdown of the total initial expenses, as well as the present value of future cash flows and the NPV. Under the baseline methodology, the NPV for this project is -$2.26 billion.

III.B Monte Carlo Analysis of the Variation in NPV

In order to come up with a more robust valuation, we manipulate the variables mentioned above and highlighted in the table in order to obtain a range of values for NPV. The most important output from our Monte Carlo simulations is the annualized volatility of NPV. In order to simulate a realistic range of possibilities for the NPV scenario, each of the variable inputs to the model is set to a distribution, primarily uniform, lognormal or normal. These ranges are then used as inputs in a Monte Carlo simulation, which varies the NPV calculation according to the different cash flows. We run 20,000 simulations and extract two parameters of the resulting distributions of NPV – the annualized standard deviation of the Present Value of all revenues, which approximately equals 30%, and the annualized standard deviation of expected total costs of the system, which approximately equals 20%. These two standard deviations are expected to best estimate the variations in both present value of revenues and expected total costs from all possible scenarios. They are used in the calibration of the ROA models below.

III.C Binomial Option Valuation Model – Simple Option to Enter

Based on the annualized volatility from the NPV distribution above, we build a binomial tree. The stock price of $8.7 billion is the present value of all the future cash flows generated by selling the energy, which is primarily determined by price per kilowatt-hour and is varied in the sensitivity analysis. The exercise price of about $11 billion reflects all of the current costs enumerated above, including launch costs, assembly expenses and the system cost, all of which are primarily dependent on the system mass. The interest rate is set approximately to the risk-free rate, which is 4%. We use an annualized volatility of 30%, which corresponds to the annualized standard deviation of the present value of revenues from the Monte Carlo simulations as described in II.B. For simplicity, we use a three-periods (t = 0,1,2) model with present time being 0 and each time period equaling 2.5 years, which results to the five-year model.

Two possible directions for the revenue are identified: the *Up* movement indicates that the revenue of the venture increases while the *Down* movement simply indicates that the revenue decreases. Based on the simple binomial approach (Cox, Ross & Rubinstein, 1979), the *Up* movement equals the exponent of annualized standard deviation (in our case 30%) times the square root of the length of time period (in our case 2.5). The *Down* movement equals one over the *Up* movement. The probability of *Up* movement p_{up} is calculated by the following equation:

$$p_{up} = \frac{\text{EXP}(Rate_{\text{interest}} \times T_{\text{interval}} - Down)}{Up - Down}$$

The probability of *Down* movement equals 1 – p_{up}. The summary of these parameters can be found in Table III.

We determine that, without loss of generality, the binomial tree can be recombining, which means that an *Up* movement followed by a *Down* movement results in the same output as a *Down* movement followed by an *Up* movement. The tree is expanded based on the probability of each movement. The option to expand or abandon is a traditional and frequently used option. For a capital-intensive project such as this, one may have to spend $50 billion over the lifetime of the project, but not all of it today (Tan, 2009). One can wait to see whether, for example, energy prices go up later on so that revenues increase, rather than funnel money into a negative NPV project or abandon it at the very beginning. In the case of SSP, there is a minimum threshold of price that makes the option of expanding feasible. This threshold is determined to be a price of 19 cents per kilowatt hour, and the project can be continued or abandoned in five years based on whether or not it meets that threshold. In this case, we decide to make the option for five years from now. The option has value when the present value of revenues, after a series of events, is greater than the total system cost. Figure I illustrates the results of the binomial tree based on 30% volatility. As seen in Figure I, the value of the project, once we account for the option to enter, equals \$2.26 billion.

III.D Binomial Option Valuation Model – Rainbow Option

The ROA model in III.C assumes that total system costs, which serve as the exercise price for the option in Table III, are constant. This estimate of costs five years from now shows substantial variation based on variations in the parameters in our Monte Carlo simulation. This variation is represented by an annualized standard deviation of approximately 20%. To better capture multiple sources of uncertainty, we decide to incorporate the impact of this variation in total costs into the valuation model. We build a second binomial tree for total costs including system cost, assembly expenses, and launch expenses. Assigning *Up* and *Down* movements to the costs and using a 20% annualized standard deviation that we got from the Monte Carlo simulation of costs, we calculate a range of costs from \$5.8 to 20 billion within two time periods of 2.5 years each.

The combined Rainbow Option tree consists of four branches for the first period and sixteen branches in the second period, incorporating the different combinations from adding the possibilities in the two major variables. These results are presented in Figure II. Compared to the \$2.26 billion project value given by the simple binomial tree model, the project value in the Rainbow Option model increases by another \$300 Million to \$2.56 billion.

III.E Discussion of Results

We derive several key conclusions in comparing the project values calculated from these three different methodologies: 1) -\$2.26 billion from NPV; 2) \$2.26 billion from the analysis of a simple option to enter; and 3) \$2.56 billion from the analysis of a Rainbow Option, which depends on two sources of uncertainty. First, the difference between the value calculated using classic NPV and the project value calculated using Rainbow Option Analysis equals

$4.82 billion, which suggests that the flexibility to make decisions in the future adds a tremendous amount of value to capital-intensive projects, especially in highly uncertain emerging ventures like SSP. Second, the value of flexibility is not recognized without the aid of advanced financial modeling tools such as ROA. Third, by using advanced financial models to appreciate the values of flexibility, corporations will have incentives to structure investment projects in stages or other ways that maximize the flexibility to respond to future uncertainty. In our case, the decision to launch the system is done five years in the future rather than today, which allows a company to capture the upside when energy prices go up with limited downside when energy prices go down.

IV. Further Research Opportunities

IV.A Project Funding

Our research mainly focuses on improving the effectiveness of the financial valuation process of SSP ventures, which will be beneficial in the venture funding process. The ability to abandon the project at early state to eliminate future high investment costs is attractive to investors. Traditional funding methods involve steps like warm referrals from the investor's trusted sources, or summits that enable investors meet companies face-to-face. Due to the special characteristics of an SSP venture (high up-front investment with huge amount of intangible value hidden under managerial decisions) we think that the funding for SSP requires a distinctive financing strategy (Xin, et al., 2009). Other alternative funding schemes such as emphasizing the environmental benefits could be further explored to obtain political supports on initial investment funding. (Jenkins, 2009)

IV.B Extraterrestrial Sources of Building Materials

In the case of SSP, launch materials and installation costs play significant roles in determining the feasibility and profitability of SSP. Other than the conventional approach we choose to adopt in the scope of this research, there are other non-conventional launching methods that should be considered to reduce the launching cost, namely harvesting materials from the Moon or Phobos (Weinstein, 2003). We are able to broadly compare the conventional launching from Earth and the opportunity to build solar panels by borrowing certain materials from the Moon and Mars or launch from Moon or Mars (Mankins, 1997).

During conventional launching, construction materials are carried first to Low Earth Orbit (LEO) by using reusable launching vehicles, and then slowly transferred from LEO to GEO over the course of several years. For this launch method, a 4 gigawatt capacity station would weigh about 80,000 metric tons assuming a solar panel mass of 20 kg/kilowatt, which means that between 40 and 150 heavy-lift launching vehicles are needed to send materials up to LEO. From there, Ion Propulsion Vehicles-first used as the main engines in NASA's Deep Space 1 that launched in 1998-will push the arrays up to GEO. This leads to approximately a total launch cost of around $11 billion for low weight panels only.

Alternatively to the conventional launch approaches, by harvesting materials from space, particularly the Moon or Phobos, launch costs are potentially much lower. The use of lunar resources would be significantly cheaper than Earth-based material for a system with as few as thirty systems of 10 gigawatt power each.

Since this concept relies less on human presence in space and more on self-replicating systems on the lunar surface under remote control of workers stationed on Earth, this proposal suffers from the current lack of such automated systems and should be explored in the future. We expect to further valuate this venture based on alternative launching methods and with automated systems once the technology becomes promising. On the other hand, potential risks resulting from the unresolved issue over the ownership of the moon or extraterrestrial objects needs to be addressed in the future research.

IV.C Using SSP for Synthetic Fuel

Another potential future research topic is harvesting synthetic fuel as a byproduct of SSP to reduce the carbon footprint resulting from increased transportation (Weinstein, 2008). Given the currently expensive synthetic fuel production process, SSP could play a significant role in obtaining synthetic fuel from a more efficient process. In the first step, CO_2 would be converted into carbon monoxide by using the "cerium-oxide-based" system. This two-chambered machine would use a rotating cerium-oxide ring and a parabolic mirror that employs solar energy to get oxygen from cerium-oxide and then pump out the oxygen. Then the de-oxygenated ring could be used in the other chamber to generate carbon monoxide. Second, a similar process could be used to convert water into hydrogen with the help of solar power. Lastly, mirrors could be used to heat chemical arrays to 400 degrees Celsius to form calcium carbonate by reacting CO2 and calcium oxide. After a few more reactions involving zinc oxide and calcium oxide, CO2 and solar power produce a synthetic fuel called Syngas and zinc oxide (World in 21st Century, 2010). With SSP assistance in synthetic fuel production, we could leverage the potential of Synthetic Fuel and make it more available for future energy consumption.

V. Summary

This research project used Real Option Analysis to value a prospective business venture that would build and operate a large-scale SSP system. The entire project was represented as a series of decisions in a binomial tree calibrated using observable data from relevant markets and Monte Carlo simulations. The identification and modeling of market uncertainties by these methods allowed us to develop a more accurate valuation of this business venture. By adopting advanced and flexible financial tools, we believe that it will become evident that large-scale SSP is a viable business venture. In addition to monetary uncertainties (i.e. the prices of oil and steel), non-monetary factors such as the global importance of sustainability and strategic energy security also add intangible value to this venture.

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Appendix

Assumptions

Launch cost to GEO per kg: Currently, the most expensive source of uncertainty for the model is launching costs. The cheapest options available are in Russia. The cheapest rocket is Dnepr, with an estimated launch price of $15 million ($2,000 US), which, considering the 4,400 kg capacity of the rocket leads to an estimated payload cost of $3,409/kg. As more and more options become readily available, launch costs will decrease, as they are expected to over the next 5-10 years. A major source of value for our Real Options Analysis is that the launch costs will be significantly lower in future years than they are today. For our simulation, we used a range of $500-$3,409/kg, which is in line with industry expectations. The static NPV model used a cost of $3,409.

Specific power density kg/kW: Based on a chapter on photovoltaic from Georgia Tech, we chose the lowest cost thin film with a specific power density of 1256 watts per kilogram. In order to get kg/kW, we took 1000/1256 = 0.796. Since this is already feasibly and currently the best efficiency for photovoltaic, we set the range at 0.5 to 0.79, since technology should help specific power density to decrease in the future. The static NPV model used 0.7961

Price per Watt of installed power: Previous studies have shown this could be anywhere from as high as $20 to as low as $1. The distribution for this was therefore uniform, because there was no reason to believe otherwise. For the NPV models, this was $10.

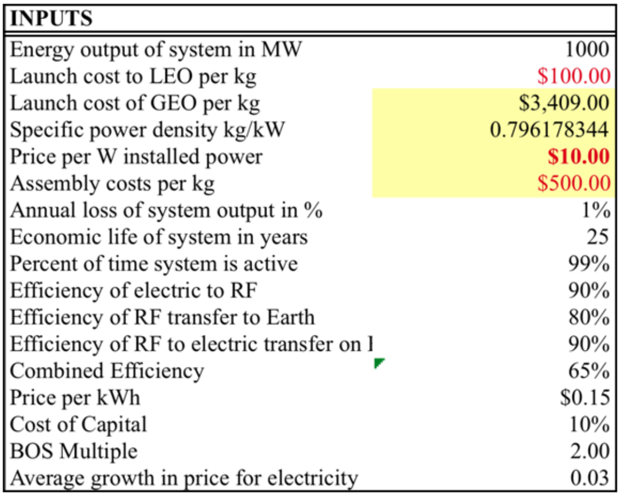
Assembly costs per kg: Assembly costs per kg is a uniform distribution with parameters of $50-$1,000. In the static NPV, this was set at $500.

Price per kWh: Currently, the break-even price per kWh that would make the NPV equal to zero is 19 cents. The price per kWh is currently around 10 cents. A number of states, however, have issued legislation that a certain percentage of their power come from renewable energy source including SSP, and have shown that they are willing to pay a steep premium, up to 30 cents in some states, for the renewable energy. Because this is the primary determinant for revenue in the future, a number of different scenarios were run with various ranges in order to get a range of NPV. The static NPV model used 15 cents to get an NPV of negative $2.26 billion. If the price were set at 30 cents, the NPV would be positive $6.44 billion.

Average growth in price for electricity: This caused some issues for us. In our preliminary research, we found that the majority of base load power is currently produced by coal, while the majority of peak load power is produced by natural gas. The ten-year average volatility of coal, based on the returns of the front-month futures contract QZ1 was 25.28%. This volatility represents a basis for off-peak volatility of power prices. The twenty-year average volatility of natural gas, based on the ticker NG1, was found to be 57.43%, which represents a basis for the on-peak volatility of power prices. While the average volatility for power prices could be averaged to about 40%, this is far too high of a volatility to take as an aggregate amount. Since we use a single number for our average growth in the price for electricity, rather than a different randomly generated number for each year, the standard deviation of the average growth should be significantly less. This is based on some general principals of the standard error of the geometric mean.

Table I
Assumptions for Initial NPV Calculation

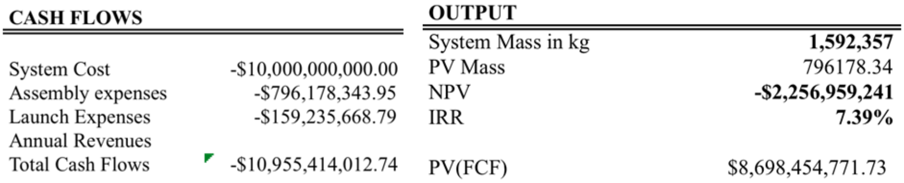
The variables launch cost from GEO per kg, specific power density kg/kilowatt installed power, price per watt installed power, assembly cost per kg, price per kilowatt-hour (kWh) and annual growth in price for electricity are those that were later modeled in the simulations of NPV. The inputs that were not simulated were those found to be relatively standard in valuations of this nature, including a combined efficiency of 65%, which is the product of the efficiencies of electricity transfer over various stages from space to the rectennas, a 1% annual loss of system output, a useful life of 25 years, and a Balance of System multiple (BOS) of 2. BOS measures the combined weight of the system relative to the power generation system.



INPUTS	
Energy output of system in MW	1000
Launch cost to LEO per kg	$100.00
Launch cost of GEO per kg	$3,409.00
Specific power density kg/kW	0.796178344
Price per W installed power	**$10.00**
Assembly costs per kg	$500.00
Annual loss of system output in %	1%
Economic life of system in years	25
Percent of time system is active	99%
Efficiency of electric to RF	90%
Efficiency of RF transfer to Earth	80%
Efficiency of RF to electric transfer on I	90%
Combined Efficiency	65%
Price per kWh	$0.15
Cost of Capital	10%
BOS Multiple	2.00
Average growth in price for electricity	0.03

Table II
Initial Expense Breakdown and Simple NPV

Cash flows were projected for the useful life of 25 years, with annual revenues equal to the output * 24 * 365 * (1-the annual loss in the system of 1%) * the price per kilowatt-hour (which, due to the variance, we modeled different ranges for) * (1 + the growth in price of electricity)^the year * percent of time active * combined efficiency. We set the cost of capital used to discount all future cash flow to 10%. The output below shows the breakdown of the total initial expenses, as well as the present value of future cash flows and the NPV.

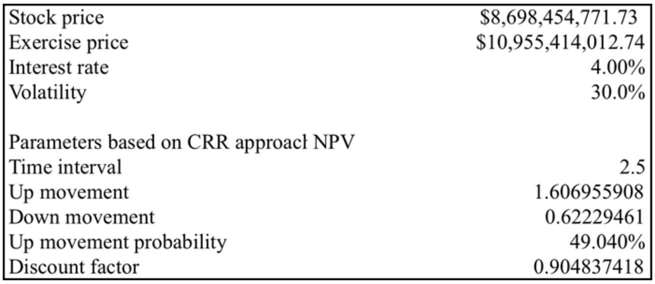


CASH FLOWS	
System Cost	-$10,000,000,000.00
Assembly expenses	-$796,178,343.95
Launch Expenses	-$159,235,668.79
Annual Revenues	
Total Cash Flows	-$10,955,414,012.74

OUTPUT	
System Mass in kg	**1,592,357**
PV Mass	796178.34
NPV	**-$2,256,959,241**
IRR	**7.39%**
PV(FCF)	$8,698,454,771.73

Table III
Parameters for Simple Binomial Tree

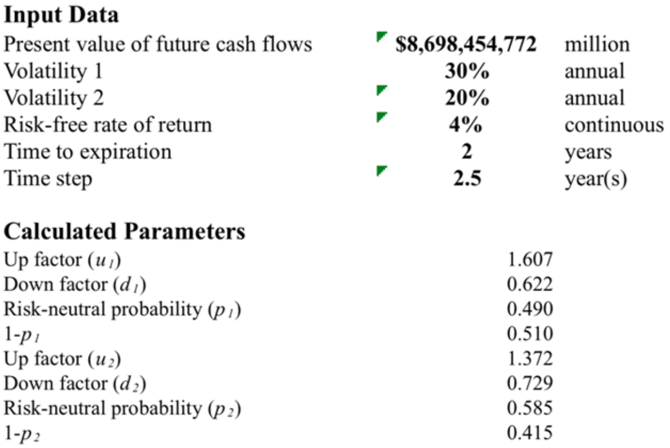
The stock price of $8.7 billion is the present value of all the future cash flows generated by selling the energy, whose main input is price per watt of installed power, which was varied in the sensitivity analysis. The exercise price of about $11 billion includes all the current costs enumerated above, including launch costs, assembly expenses and the system cost, all primarily dependent on the system mass. The interest rate was set at approximately the risk free rate, at 4%, and the average volatility of 20% was used. The summary of the result was presented in the table below.



Stock price	$8,698,454,771.73
Exercise price	$10,955,414,012.74
Interest rate	4.00%
Volatility	30.0%
Parameters based on CRR approacl NPV	
Time interval	2.5
Up movement	1.606955908
Down movement	0.62229461
Up movement probability	49.040%
Discount factor	0.904837418

Table IV
Rainbow Options Assumptions and Inputs

The basic assumptions are based on the results we derived from the earlier DCF models. Such as baseline NPV of $8.7 billion, annualized volatilities, and risk-free rate, etc,. For the parameters used in calculation that monitors the future projection, factors along with probabilities are assumed as we did for the simple binomial models. Based upon the assumptions mentioned in the tables above, the binomial tree was built around the total costs of the project and the NPV.
All the assumptions and NPV are listed below.



Input Data		
Present value of future cash flows	**$8,698,454,772**	million
Volatility 1	**30%**	annual
Volatility 2	**20%**	annual
Risk-free rate of return	**4%**	continuous
Time to expiration	**2**	years
Time step	**2.5**	year(s)

Calculated Parameters	
Up factor (u_1)	1.607
Down factor (d_1)	0.622
Risk-neutral probability (p_1)	0.490
1-p_1	0.510
Up factor (u_2)	1.372
Down factor (d_2)	0.729
Risk-neutral probability (p_2)	0.585
1-p_2	0.415

Option Valuation Lattice

Time period	0	1	2
PV(FCF) Tree	$8,698,454,772	$13,978,033,287	$22,462,083,176
		$5,413,001,519	$8,698,454,772
			$3,368,481,669
Option to Enter Tree	$2,265,628,967	$5,105,863,587	$11,506,669,163
		$0	$0
			$0

Figure I
Binomial Valuation Lattice of Simple Option to Enter

The figure presents the results from the evaluation of an option to launch the project that depends on one source of uncertainty – the present value of future revenues, with an annualized volatility of 30%. Each time period equals 2.5 years. All parameters required for calibrating the tree are presented in Table III. The terminal payoffs of the option in Period 2 equal Max(PV(FCF) – Total Costs, 0).

Option Valuation Lattice

Time period	0	1	2
Valuation of underlying asset			$1,841,509,563
($ million)			$11,506,669,163
			$11,506,669,163
		$8,884,410,789	$16,641,629,369
			$0
			$0
			$0
		$550,538,780	$2,878,000,965
	$2,556,700,567		$0
			$0
			$0
		$550,538,780	$2,878,000,965
			$0
			$0
			$0
		$0	$0

Figure II
Binomial Valuation Lattice of Rainbow Option

The figure presents the results from the evaluation of a Rainbow Option to launch the project that depends on two sources of uncertainty: 1) the present value of future revenues, with an annualized volatility of 30%, and 2) the total system costs, with an annualized volatility of 20%. Each time period equals 2.5 years. All parameters required for calibrating the tree are presented in Table IV. The terminal payoffs of the option in Period 2 equal Max(PV(FCF) – Total Costs, 0). The 16 terminal nodes correspond to the 16 combinations of four possible movements for PV(FCF) – UpUp, UpDown, DownUp, and DownDown, and four possible movements for Total Costs – UpUp, UpDown, DownUp, and DownDown.