A Rational Roadmap for Developing a First Revenue Space Solar Power Satellite

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FIRM INTRODUCTION
Overview:
- An engineering services firm with offices in Atlanta, Georgia (HQ) and Washington, D.C.
- Spin-off from the Georgia Institute of Technology founded in 2000
- Approximately +$2M annual revenues from sales of engineering services and software
- 85% of SEI staff members hold degrees in engineering or science
- Three major divisions: Engineering, Commercial, and Software

Core Competencies:
- Advanced concept synthesis for launch and in-space transportation systems
  - Including engineering design and analysis, new concept design, independent concept assessment, life cycle analysis, and programmatic evaluation
- Financial engineering analysis for next-generation aerospace applications and markets
- Technology impact analysis and quantitative technology portfolio optimization
- Commercial development of space
- Media materials related to space
- Engineering software development

Clients:
- NASA, U.S. DoD, commercial space companies

SPACEWORKS ENGINEERING, INC. (SEI)
SPACEWORKS: KEY CUSTOMERS BY DIVISION
REUSABLE LAUNCH VEHICLES
HUMAN SPACE EXPLORATION
**Space Venture Accelerator**
We look to leverage internal and external resources to champion our own ventures.

**NanoLaunch Services [incubator study]**
SpaceWorks Commercial is examining the market demand and launch supply for small satellites, focusing on the microsatellite (10-100 kg) and nanosatellite (1-10 kg) markets.

**FastForward Study Group [incubator study]**
The FastForward study group is an ad-hoc study group involving pre-competitive analysis and assessment of future global high speed point-to-point (PTP) passenger and cargo services.

**Google Lunar X PRIZE [partnership support]**
SpaceWorks Commercial is assisting Astrobotic Technology, Inc., one of the leading contenders for the Google Lunar X PRIZE, to analyze the commercial potential of future lunar robotic missions.

**Space Solar Power Economics [incubator study]**
SpaceWorks Commercial continues to examine the potential cost and economics of Space Solar Power (SSP). This includes the cost of a demonstrator and near-term, operational system.

**Spaceport Field Guide [tool development]**
SpaceWorks Commercial has developed a Google Earth plug-in that offers a database of worldwide launch sites.

SPACEWORKS COMMERCIAL: CURRENT PROJECTS
FutureAssist Solutions

Accelerate your aerospace idea or invention from a unique vision to feasible reality

The “Advanced” Package
Refine the design and execute the business strategy

The “Standard” Package
Engineer the concept

The “Basic” Package
Develop the idea

Aerospace technical, economic, and graphics services in cost effective, fixed-price pre-packaged bundles

www.spaceworkscommercial.com
- The viability of Space Solar Power (SSP) to compete and supply electricity for consumption on the Earth has been debated for quite sometime.

- SpaceWorks Commercial has been analyzing the economics of SSP
  - Past experience in space economics and transportation analysis of SSP (Fresh Look, SERT, etc.)
  - Presentation at Space Power Canada IAC 2008/9
  - Assisted in 2010 IAA study on SSP (J. Mankins)
  - Review of previous economic analysis (1970s to today)
  - Some new analyses (parametric for full-scale system and more in-depth for pilot plan)

- Specific Analysis
  - Full scale economic analysis
    - Top level economic analysis for a notional Space Solar Power company (full up system) and analyzing breakout between space transportation costs and all other costs (terrestrial markets)
    - Global electricity price analysis including niche customer analysis (humanitarian, remote sites, military, etc.) to determine price points and quantity/schedule of demand
    - Three top-level system economic analysis
  - SSP First Revenue Satellite (FRS) economic analysis
    - Hybrid public-private system, interim 1-2 satellite system

SPACEWORKS COMMERCIAL SSP INTEREST
GLOBAL NICHE MARKETS AND POWER FINANCING
GLOBAL ELECTRICITY RETAIL PRICE (2009, 1Q)

- **USA**
  - Household: $0.114/kWh
  - Industry: $0.070/kWh

- **UK**
  - Household: $0.232/kWh
  - Industry: $0.146/kWh

- **Chinese Taipei**
  - Household: $0.089/kWh
  - Industry: $0.067/kWh

- **South Korea**
  - Household: $0.089/kWh
  - Industry: $0.060/kWh

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  - Household: $0.114/kWh
  - Industry: $0.070/kWh

- **UK**
  - Household: $0.232/kWh
  - Industry: $0.146/kWh

- **South Korea**
  - Household: $0.089/kWh
  - Industry: $0.060/kWh

- **Spain**
  - Household: $0.218/kWh
  - Industry: $0.125/kWh

- **France**
  - Household: $0.169/kWh
  - Industry: $0.060/kWh

- **Turkey**
  - Household: $0.165/kWh
  - Industry: $0.148/kWh

- **Uganda**
  - Domestic: $0.23/kWh

- **Nigeria**
  - Household: $0.059/kWh
  - Industry: $0.065/kWh

- **Brazil**
  - Household: $0.153/kWh

- **South Africa**
  - Domestic: $0.055/kWh

- **Mexico**
  - Household: $0.096/kWh
  - Industry: $0.126/kWh

- **Nigeria**
  - Household: $0.059/kWh
  - Industry: $0.065/kWh

- **Uganda**
  - Domestic: $0.23/kWh

- **Spain**
  - Household: $0.218/kWh
  - Industry: $0.125/kWh

- **Turkey**
  - Household: $0.165/kWh
  - Industry: $0.148/kWh

- **Brazil**
  - Household: $0.153/kWh

- **South Africa**
  - Domestic: $0.055/kWh

- **New Zealand**
  - Household: $0.164/kWh
  - Industry: $0.071/kWh

Source: Key World Energy Statistics, IEA (excluding red colored fonts)
源：《非洲电力零售价格比较研究》 – 2009年12月，UPDEA

电力零售价格在非洲（2009年）
**Case Study Overview**

<table>
<thead>
<tr>
<th>Organization</th>
<th>The government of Republic of Uganda</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>Uganda (2009 ~ 2013)</td>
</tr>
<tr>
<td>Purpose</td>
<td>To increase access to energy in rural Uganda, rural energy infrastructure (electricity distribution). small scale renewable energy generation plants, household and institutional solar PV system and related technical assistance and training</td>
</tr>
<tr>
<td>Price</td>
<td>N/A</td>
</tr>
<tr>
<td>Loan Details</td>
<td>30-years term with no interests, Credits do carry a small service charge of 0.75 % on disbursed balances.</td>
</tr>
</tbody>
</table>

**Financing**

<table>
<thead>
<tr>
<th>Total Project Cost</th>
<th>$105 M</th>
<th>100.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>International Development Association</td>
<td>$75 M</td>
<td>71.4%</td>
</tr>
<tr>
<td>Foreign Private Commercial Sources</td>
<td>$25 M</td>
<td>23.8%</td>
</tr>
<tr>
<td>Borrower (Republic of Uganda)</td>
<td>$5 M</td>
<td>4.8%</td>
</tr>
</tbody>
</table>

Source: the World Bank (http://web.worldbank.org)

**CASE STUDY 1:**

**UGANDA - ENERGY FOR RURAL TRANSFORMATION APL-2**
**Case Study Overview**

<table>
<thead>
<tr>
<th>Organization</th>
<th>Botswana Power Corporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>Botswana (2009 ~ 2014)</td>
</tr>
<tr>
<td>Purpose</td>
<td>Developing reliable supply of electricity and promoting alternative energy sources for low-carbon growth, Construction of a 600 MW (4 x 150 MW) coal-fired power station, Preparing a low-carbon growth strategy (50MW Solar targeted by 2016)</td>
</tr>
<tr>
<td>Price</td>
<td>5 cents/kWh (20 cents/kWh for Solar Power)</td>
</tr>
<tr>
<td>Loan Details</td>
<td>40-years term with no interests (IBRD), 20-years term with 1.336% interests (ADB), Financial IRR = 6.7%</td>
</tr>
</tbody>
</table>

**Financing**

<table>
<thead>
<tr>
<th>Total Project Cost</th>
<th>$905.4 M</th>
<th>100.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBRD – World Bank</td>
<td>$98.2 M</td>
<td>10.8%</td>
</tr>
<tr>
<td>African Development Bank (ADB)</td>
<td>$139.3 M</td>
<td>15.4%</td>
</tr>
<tr>
<td>Middle Income Country Trust Fund Grant</td>
<td>$0.6 M</td>
<td>0.1%</td>
</tr>
<tr>
<td>ICBC – Standard Bank</td>
<td>$535.7 M</td>
<td>59.2%</td>
</tr>
<tr>
<td>Borrower (The Government of Botswana)</td>
<td>$131.6 M</td>
<td>14.5%</td>
</tr>
</tbody>
</table>

Source: African Development Bank (http://www.afdb.org)

**CASE STUDY 2:**

**BOTSWANA - MORUPULE B GENERATION AND TRANSMISSION PROJECT**
### Case Study Overview

<table>
<thead>
<tr>
<th>Organization</th>
<th>Argentina Secretary of Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>Argentina (1999 ~ 2011)</td>
</tr>
<tr>
<td>Purpose</td>
<td>Providing electricity for lighting and radio &amp; TV to about 70,000 rural households and 1,100 provincial public service institutions, installation of solar home system and decentralized energy supply, installation of Wind Home System (WHS) units in 2 small rural communities</td>
</tr>
<tr>
<td>Price</td>
<td>$8 ~ 10 per month, receiving 3 kWh monthly, (With Equipment Cost of about $3.56/month, $1.48/kWh per month)</td>
</tr>
<tr>
<td>Loan Details</td>
<td>15-years term with 0.87% interests ($30M from IBRD), 30-years term with no interests ($50M from IBRD)</td>
</tr>
</tbody>
</table>

**Financing**

<table>
<thead>
<tr>
<th><strong>Total Project Cost</strong></th>
<th><strong>$170.5 M</strong></th>
<th><strong>100.0%</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>IBRD – World Bank</td>
<td>$ 80.0 M</td>
<td>46.9%</td>
</tr>
<tr>
<td>GEF (Grant)</td>
<td>$ 10.0 M</td>
<td>5.9%</td>
</tr>
<tr>
<td>Government’s Fund (FEDEI)</td>
<td>$ 26.5 M</td>
<td>15.5%</td>
</tr>
<tr>
<td>Concessionaires</td>
<td>$ 43.2 M</td>
<td>25.3%</td>
</tr>
<tr>
<td>Customers (Households or Institution)</td>
<td>$ 10.8 M</td>
<td>6.3%</td>
</tr>
</tbody>
</table>


### CASE STUDY 3: ARGENTINA - RENEWABLE ENERGIES IN THE RURAL MARKET (PERMER)
## Case Study Overview

<table>
<thead>
<tr>
<th>Organization</th>
<th>The Dongying Shengdong EMC (Commercial Company)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>China (2004)</td>
</tr>
<tr>
<td>Purpose</td>
<td>Building power stations that are capable of burning waste gases, provided by customers for free or at very low cost</td>
</tr>
<tr>
<td>Price</td>
<td>3.65 ~ 5.47 cents per kWh</td>
</tr>
<tr>
<td>Loan Details</td>
<td>1 year term, 90% of loan was guaranteed by GEF (Global Environment Facility) Funds with World Bank</td>
</tr>
</tbody>
</table>

### Financing

<table>
<thead>
<tr>
<th>Total Investment</th>
<th>$900 K</th>
<th>100.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loan from Commercial Bank</td>
<td>$850 K</td>
<td>94.4%</td>
</tr>
<tr>
<td>Internal Funding</td>
<td>$50 K</td>
<td>5.6%</td>
</tr>
</tbody>
</table>

Source: ESMAP website (http://www.esmap.org), Financing energy efficiency: lessons from Brazil, China, India, and beyond

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### CASE STUDY 4:

**CHINA - 1.9 MW POWER STATION AT A COKING PLANT**
POWER REQUIRED FOR US FORCES IN FORWARD-DEPLOYED REGIONS

Note: Electric power required is calculated using fuel consumption of 4 gallon/hour.
Source: GAO 09-300, DOD Needs to Increase Attention on Fuel Demand Management at Forward-Deployed Locations
- Forward bases rely on electrical generators, externally delivered fuel
  - A single typical 60-kilowatt generator burns 4 ~ 5 gallons per hour
  - Cost of Fuel (fully encumbered)
    - Iraq: $13.80/gallon, Afghanistan: $17.44/gallon
    - Other sources (Roger Leonard: $200/gallon, Tauri Group: $400/gallon, both at IAC 2010 Session IAC-10.C3.1)
  - Source: Joint Force Quarterly #57 (2nd Quarter, April 2010)

- Estimate for Electricity Cost using fuel + terrestrial generators:
  - Iraq: $0.92 / kWh
  - Afghanistan: $1.16 / kWh
  - Leonard Estimate: $13.3 / kWh
  - Tauri Estimate: $26.7 / kWh

- Space-Based Solar Power Report by National Security Space Office
  - “When all indirect and support costs are included, it is estimated that the DoD currently spends over $1 per kilowatt hour for electrical power delivered to troops in forward military bases in war regions.”

FORWARD BASE POWER COSTS
FIRST REVENUE SATELLITE (FRS) FINANCIAL ANALYSIS OVERVIEW
– Full-scale (~GW) systems may not be viable as full commercial programs
– Demonstration of operations important part of proof-of-concept

FIRST REVENUE SATELLITE (FRS)
– SSP First Revenue Satellite (FRS) as a potential better model for sustainable SSP development
– FRS would be a mid-power (~1-20 MW) in-space to ground demonstrator of SSP
– Would also demonstrate operations (multiple years after demonstration phase)
– Turn over to commercial operator for public/private service

FIRST REVENUE SATELLITE (FRS) PHILOSOPHY
– SSP First Revenue Satellite (FRS)
  – 5 MW SSP for niche markets where there is limited access to electricity
  – 10 years operations without refurbishment for a satellite

– Financial analysis modeling
  – Investigating economic viability for both government and commercial customers with different pricing options
  – Based on CABAM2 (SEI financial analysis tool)
  – Two price capability (Commercial & Government), Commercial price is set to a Market Price (currently only government market)
    – Government contribution would be evenly distributed and not same to actual cost of DDT&E or Acquisition each year, only total amount is considered to calculate contributed amounts
  – Equity / Debt Financing Model: Equity Financing = Staged Input Variables
  – Price Optimization for Zero NPV along with inputs for Government Contribution, Launch Cost, and Government-Commercial Sales Proportion
  – Examine various government contribution scenarios
    – No contribution
    – 100% of DDT&E cost
    – 100% of DDT&E cost + 100% of acquisition cost

FRS MODELING OVERVIEW
1. Microwave antenna: 1-km diameter.
2. Assuming overall efficiency of 10% (intercepted sunlight to Earth electric power)
3. Two solar arrays area: 18,300 m² or 152 m diameter
4. Two arrays are fixed to the primary truss structure on the back of the transmit antenna facing the north-south axis.
5. Flat solar reflectors in elliptical 165-m 240-m rims rotate about this axis to track the Sun.
6. Mantech SRS reflectors are of space-qualified polyimide with 94% reflectivity and an NRL-patented edge treatment that prevents distortions in the large areas of material.
7. Both the antenna structure and the reflector rims are NRL large structures


**NAVAL RESEARCH LAB (NRL) 5 MW SSP CONCEPT**
1. Developed Non-recurring cost estimate for Naval Research Lab (NRL) Space Solar Power (SSP) 5 MW system
   1. System includes LEO-GEO transfer system
2. Use of NAFCOM 2007 for non-recurring cost assessment
   1. Transmission system separated from spacecraft bus (used active microwave spacecraft CERs)
   2. Assessment is deemed to be conservative estimate
3. Weight-based direct CER analogies for NASA historical satellites
4. Note: Preliminary Estimate

Table 8 – Mass Allocations, 5-MW SBSP System, LEO to GEO Transfer

<table>
<thead>
<tr>
<th>Allocation</th>
<th>Total Mass (kg)</th>
<th>Comments/Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitude Control</td>
<td>50</td>
<td>Based on Upper Stage</td>
</tr>
<tr>
<td>Command &amp; Data Handling</td>
<td>50</td>
<td>Based on Upper Stage</td>
</tr>
<tr>
<td>Communications</td>
<td>100</td>
<td>Based on Upper Stage</td>
</tr>
<tr>
<td>Mechanisms</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Energy Collection</td>
<td>20,000</td>
<td>250 W/Kg</td>
</tr>
<tr>
<td>Transmission Payload</td>
<td>10,000</td>
<td>TBD</td>
</tr>
<tr>
<td>Power Distribution &amp; Wire Harness</td>
<td>300</td>
<td>Al Wire 1.4 kg/100m2 for 36000 m2</td>
</tr>
<tr>
<td>Thermal</td>
<td>300</td>
<td>3 large pump loop systems</td>
</tr>
<tr>
<td>Misc. Mass/ Margin</td>
<td>100</td>
<td>Estimate</td>
</tr>
<tr>
<td>Total Minus Propulsion and Structure</td>
<td>31804</td>
<td>Total of Non-Scaleable Subsystems</td>
</tr>
<tr>
<td>Propellant</td>
<td>20,000</td>
<td>LEO to GEO Transfer Plus 10 Yrs NW-EW GEO Station Keeping, 6000 m/s</td>
</tr>
<tr>
<td>Propulsion</td>
<td>2,200</td>
<td>Propulsion Dry Mass</td>
</tr>
<tr>
<td>Structure</td>
<td>5,400</td>
<td>Assume 10% structure</td>
</tr>
<tr>
<td>Total Space Vehicle</td>
<td>59404</td>
<td></td>
</tr>
</tbody>
</table>


MASS ESTIMATE OF NRL 5 MW SSP CONCEPT
### Naval Research Lab (NRL) Space Solar Power (SSP) 5 MW system

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Development (to TRL 6)</td>
<td>$0.0</td>
<td>$0.0</td>
<td>Assumed to be 0</td>
</tr>
<tr>
<td>Phase A/B</td>
<td>$60.1</td>
<td>$18.4</td>
<td>3% of total main hardware</td>
</tr>
<tr>
<td>TOTAL MAIN HARDWARE</td>
<td>$2002.8</td>
<td>$612.3</td>
<td></td>
</tr>
<tr>
<td>Spacecraft Bus</td>
<td>$982.6</td>
<td>$285.4</td>
<td></td>
</tr>
<tr>
<td>Transmission</td>
<td>$518.9</td>
<td>$192.9</td>
<td></td>
</tr>
<tr>
<td>Systems Integration</td>
<td>$501.3</td>
<td>$134.0</td>
<td></td>
</tr>
<tr>
<td>TOTAL WRAPS</td>
<td>$936.2</td>
<td>$288.5</td>
<td></td>
</tr>
<tr>
<td>Fee</td>
<td>$207.2</td>
<td>$63.8</td>
<td></td>
</tr>
<tr>
<td>Program Support</td>
<td>$228.0</td>
<td>$70.2</td>
<td></td>
</tr>
<tr>
<td>Contingency</td>
<td>$501.6</td>
<td>$154.5</td>
<td></td>
</tr>
<tr>
<td>GROUND SYSTEM</td>
<td>$20.0</td>
<td>$15.0</td>
<td>Estimate</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$3,109.1</td>
<td>$1,546.2</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- 130% STH on all hardware elements
- Fee: 10%, Program Support: 10%, Contingency: 20%, in-space dry mass = 39,404 kg

1. **DDT&E Cost per kg (in-space dry mass)** = $78,396 / kg
2. **Acquisition Cost per kg (in-space dry mass)** = $38,859 / kg
3. **DDT&E + Acquisition Cost per kg (in-space dry mass)** = $117,255 / kg

### Space Hardware Cost Comparisons:
- SSP-ISS Demo E: $90,909/kg
- ISS: $115,259/kg
- NEAR: $181,083/kg
- Mars Pathfinder: $430,787/kg
- Lunar Prospector: $340,569/kg
- Landsat-7: $252,941/kg
- Iridium Satellite: $7,257/kg
- 1970 DOE/NASA SPS: $356/kg (w/o DDT&E)

**NON-RECURRING COST OF NRL 5 MW SSP CONCEPT**
CABAM2 FINANCIAL MODEL FOR SSP FRS
### Price Information

<table>
<thead>
<tr>
<th>Price Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price for Commercial Customers</td>
<td>$0.050/kWh</td>
</tr>
<tr>
<td>Price for Government Customers</td>
<td>Sweep Variable</td>
</tr>
<tr>
<td>Commercial Sales Proportion</td>
<td>0.0 %</td>
</tr>
<tr>
<td>Government Sales Proportion</td>
<td>100.0 %</td>
</tr>
<tr>
<td>Market Price</td>
<td>$0.0500/kWh</td>
</tr>
</tbody>
</table>

- **Same/different price to Commercial customers**
- **Price Optimization** (govt. price larger than commercial price)
- **Sensitivity Analysis with 0~100% Government Customers Proportion**

### Optimization to find maximum NPV using prices

i.e. Electricity price by conventional generator in African countries
### Economics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflation Rate</td>
<td>2.10 %</td>
</tr>
<tr>
<td>Tax Rate</td>
<td>35.00 %</td>
</tr>
<tr>
<td>Average Annual Interest Rate, Nominal</td>
<td>4.00 %</td>
</tr>
<tr>
<td>Average Annual Interest Rate, Real</td>
<td>1.81 %</td>
</tr>
<tr>
<td>Capital-on-hand at Program Start ($M)</td>
<td>0</td>
</tr>
<tr>
<td>Risk-Free Rate</td>
<td>4.00 %</td>
</tr>
</tbody>
</table>

### Depreciation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Years</td>
<td>10</td>
</tr>
<tr>
<td>Cost to Depreciate (%)</td>
<td>100.00 %</td>
</tr>
<tr>
<td>Salvage Value (%)</td>
<td>0.00 %</td>
</tr>
</tbody>
</table>

Same to Risk-Free Rate

No Initial Capital

### Equity Financing

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amounts ($M)</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Return (%)</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Dividends Rate to Cash Flow

### Debt Financing

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond Term (Years)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

- Amounts of debt financing is assumed to cover all deficit after equity financing.
- Debt is repaid by the end of program.

**INPUT VARIABLES: ECONOMICS & FINANCING**
### Program Schedule
- Program Start Year: 2015
- Initial Operating Year: 2020
- Program End Year: 2029

### DDT&E Schedule
- DDT&E Start Year: 2015
- DDT&E End Year: 2017

### Production/Acquisition Schedule
- Production/Acquisition Start Year: 2018
- Production/Acquisition End Year: 2019

### Facility Development Schedule
- Facility Development Start Year: 2018
- Facility Development End Year: 2019

### Fiscal Year
- Equity Financing
- Debt Financing

### DDT&E
- Fiscal Year: 2014 to 2019

### Production/Acquisition
- Fiscal Year: 2018 to 2019

### Facility Development
- Fiscal Year: 2018 to 2019

### Operations
- Fiscal Year: 2019 to 2029

**INPUT VARIABLES: PROJECT SCHEDULE**
### SSP System Characteristics

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Power per Solar Power Satellite</td>
<td>5 MW</td>
</tr>
<tr>
<td>Efficiency to Grid</td>
<td>100.0%</td>
</tr>
<tr>
<td>Nominal Duty Cycle</td>
<td>100.0%</td>
</tr>
<tr>
<td>Total Power Operating</td>
<td>5 MW</td>
</tr>
</tbody>
</table>

### Launch Mass

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Base mass of each SPS</td>
<td>59.4 MT</td>
</tr>
<tr>
<td>Refurbishment % per year</td>
<td>0.0%</td>
</tr>
<tr>
<td>Number of SPS per year</td>
<td>1</td>
</tr>
<tr>
<td>Total Number of SPS</td>
<td>1</td>
</tr>
<tr>
<td>Total Launch Mass</td>
<td>59.4 MT</td>
</tr>
</tbody>
</table>

### Transportation Cost

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth-to-Orbit</td>
<td>$2,694 /kg</td>
</tr>
<tr>
<td>In-Space: LEO-to-GEO</td>
<td>$0.00 /kg</td>
</tr>
</tbody>
</table>

Falcon-9 (Total = US$80 M x 2 launches)  
Sensitivity Analysis with $500/kg ~ $5,000/kg

Ground power storage and other facility costs are assumed to be provided by the market user.

### Cost Structure: Year of Cost = 2014

<table>
<thead>
<tr>
<th></th>
<th>Recurring</th>
<th>Non-Recurring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amounts per SPS</td>
<td>Operating</td>
<td>In-space Transport</td>
</tr>
<tr>
<td>Space Segment $M</td>
<td>5.00</td>
<td>0.0</td>
</tr>
<tr>
<td>Ground Segment $M</td>
<td>1.45</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Ground receiver refurbishment cost: $100K  
Ground receiver system labor: 5 x $150K  
Ground operations labor: 3 x $200K

Sensitivity Analysis with 0~100% Government Contribution

INPUT VARIABLES: SYSTEM & COST
No Government Contribution
(Equity Investment = $100M each for first three years)

Break-Even Price = $27.604 /kWh

SSP FRS: FINANCIAL PROJECTIONS FOR PURE COMMERCIAL CASE
Government Contribution = 100% DDT&E
(Equity Investment = $100M each during the acquisition)

Break-Even Price = $8.029 /kWh

SSP FRS: FINANCIAL PROJECTIONS FOR GOVT. DDT&E CASE
Government Contribution = 100% DDT&E, 100% Acquisition
(No Equity Investment Required)

Break-Even Price = $0.762 /kWh

SSP FRS: FINANCIAL PROJECTIONS FOR GOVT. DDT&E/ACQ. CASE (1)
Government Contribution = 100% DDT&E, 100% Acquisition (No Equity Investment Required)

Break-Even Price = $0.762 /kWh
DDT&E and acquisition costs are so expensive that selected 5 MW satellite can’t cover the expenses for reasonable prices
  - Large government contribution is required for reasonable price in niche market

Further analysis is possible with cheaper system, less mass, or smaller discount rates
  - If satellite cost per MWh and mass per MWh are known, optimized power for the target price (e.g. $1/kWh) can be calculated

Future Work
  - Examine alternate 5-10 MW systems (more optimized design)
  - Examine more specific customer scenarios
  - Examine additional financing schemes

First Revenue Satellite (FRS) CABAM2 Financial Modeling Outputs: Price ($/kWh) at Break-Even Point

<table>
<thead>
<tr>
<th>Government Scenario</th>
<th>Contribution Amount ($M)</th>
<th>Equity Investment</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Contribution</td>
<td>$0 M</td>
<td>$100M each for first three years</td>
<td>$27.604 / kWh</td>
</tr>
<tr>
<td>100% DDT&amp;E</td>
<td>$3,072 M</td>
<td>$100M each during Acquisition</td>
<td>$8.029 / kWh</td>
</tr>
<tr>
<td>100% DDT&amp;E 100% Acquisition</td>
<td>$4,651 M</td>
<td>No Equity Investment</td>
<td>$0.762 / kWh</td>
</tr>
</tbody>
</table>

OBSERVATIONS